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DIGITAL DELAY LINES

Introduction

Solid digital delay lines have been developed for use as serial storage elements in high speed data processing equipment. The solid digital line covers the speed range immediately above that satisfied by magnetostrictive delay lines, nominally from 2.5 to 30 mc. Delay lengths up to 1000 μ sec and storage capacities to 20,000 bits are possible.

Many different materials and processes can be utilized in digital lines. The major design approaches are described here with sufficient explanation to enable the user to choose the proper delay line for his requirement.

Pulse Characteristics

Traditionally, solid delay lines have been operated as analog devices. The information to be delayed was superimposed on a carrier wave, and the delay line was designed for optimum performance at the carrier frequency. When a line was used for digital storage, a bit consisted of a burst of r-f energy at 10 to 60 mc. Since longer lines were highly delay dispersive, subjecting the line to a video pulse resulted in a ringing output pulse,

the higher frequency components coming out first and the lower frequency components later, as illustrated in Figure 1.

Technology has now been developed to make delay lines non-dispersive, thereby allowing the storage of information in video form. The response of an ideal non-dispersive line is shown in Figure 2.

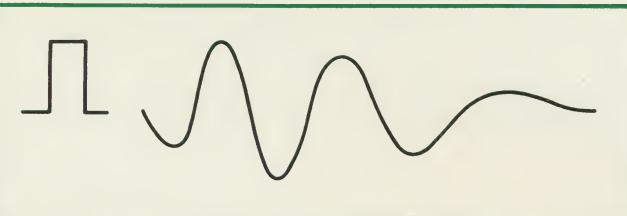


FIGURE 1

Solid standard line — showing dispersion

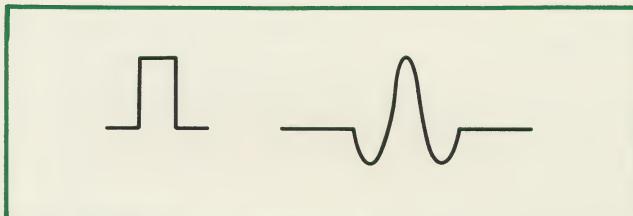


FIGURE 2

Solid digital line — non-dispersive operated in RZ mode

Since a delay line is a resonant device with a distinct point of minimum signal loss, it is necessary to use an input pulse whose frequency spectrum contains a maximum amount of energy near the center of the bandpass of the delay line. This is most easily accomplished by using a video pulse whose length is $\frac{1}{2}$ the wave length of the peak frequency of the line. If the line is operated in the RZ mode, the off time between pulses will be equal to the on time of the pulse so the maximum data rate of the line will equal the peak frequency of the line.

The delay line may also be operated in the NRZ mode. In this case, a step input results in an output dipole as shown in Figure 3.

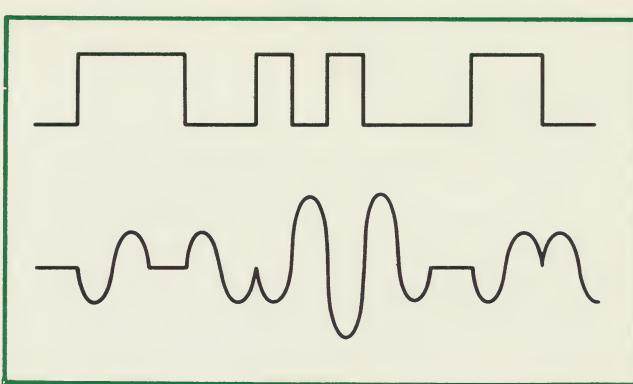


FIGURE 3

Solid digital line — non-dispersive operated in NRZ mode

Pulse Distortion

The output characteristics of a digital line are rarely ideal, so a few comments should be made about pulse distortion. There are three major sources of pulse degradation — dispersion, transducer ringing, and irregular beam propagation. In a substantially non-dispersive line, residual dispersion results in the following pulse forms, depending upon the extent of dispersion.

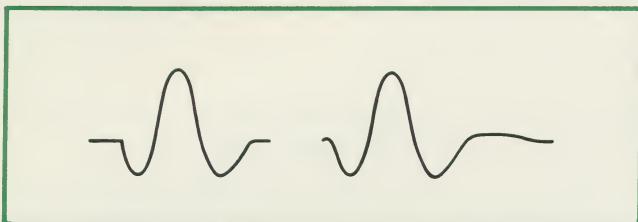


FIGURE 4
Residual dispersion

Obviously, the long trailing edges of the pulses shown limit the packing density of the pulses, and in the case

of the second pulse, the second positive hump may appear to be a signal.

Transducer ringing is caused by either improper bonding or improperly matched bonding materials. The output pulse under these conditions takes the forms shown below.

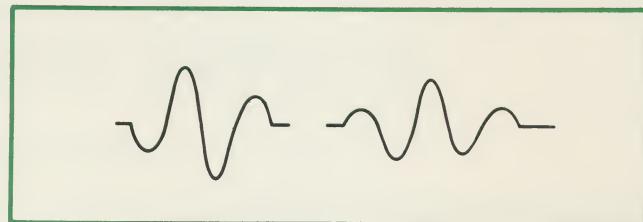


FIGURE 5
Transducer ringing

If the wave front of the acoustic pulse in the delay line is distorted by scattering, diffraction or refraction of the beam, pulse distortion will result. This distortion can take a great variety of forms and, in many cases, is not distinguishable from dispersion and ringing.

Delay Line Types and Characteristics

At the present time there are two basic delay media, fused quartz and zero T/C glass. Two basic transducer materials, quartz crystal and piezoelectric ceramic, are available. There are several varieties of each of the basic materials.

Fused Quartz

Fused quartz and fused silica have been the traditional delay media for solid delay lines. The two materials are almost chemically identical, the former being produced from natural crystalline quartz, and the latter by a high temperature chemical process. Either material is an ideal medium for a delay line because of its low acoustic loss coefficient, $1 - 2 \times 10^{-4}$ db/ μ sec-mc, otherwise stated as $1-2 \times 10^{-4}$ db/bit. The disadvantage of this material is its high temperature coefficient, -70 to -80 ppm/ $^{\circ}$ C.

Zero T/C Glass

The other major class of delay media is the zero T/C glasses. Several hundred glass compositions which exhibit a zero temperature coefficient of delay can be produced; however, only a few have loss constants low enough to allow large capacity storage of digital information. The good zero T/C glasses have loss constants in the range $4 - 7 \times 10^{-3}$ db/bit. The T/C's are generally zero at only one temperature, usually 25° C, and have a linear, positive change of T/C with temperature in the range of $+0.45$ to $+0.11$ ppm/ $^{\circ}$ C². The difference

between the delay time of a line at a given temperature from the delay time at the zero point temperature is given by

$$\Delta D = \frac{1}{2} D a(\Delta T)^2$$

where D = delay time

a = rate of change of T/C with temperature

ΔT = temperature difference from zero point temperature

ΔD is positive on both sides of the zero point.

A typical example might be:

What is the change in time delay of a 200μ sec line from -20° C to $+70^{\circ}$ C if the zero T/C glass has an acceleration, a , of $.06$ ppm/ $^{\circ}$ C² and a T/C point at 20° C.

$$D_{20^{\circ}} = 200.0000 \mu\text{sec}$$

$$D_{-20^{\circ}} = 200.0000 + \frac{1}{2} (200) (.06) 40^2 \times 10^{-6} = 200.0096$$

$$D_{+70^{\circ}} = 200.0000 + \frac{1}{2} (200) (.06) 30^2 \times 10^{-6} = 200.0054$$

Zero T/C glasses have several advantages for digital delay lines besides the good temperature coefficient. Many of these glasses have acoustic impedances nearly equal to that of the quartz crystal transducer. Ringing of the transducer is thereby held to a minimum. This impedance match also helps in achieving a bandwidth wide enough to pass the spectrum of the input pulse, thereby insuring pulse fidelity.

However, the high loss of the zero T/C glasses limits the bit capacity of the lines made from it to about 2000 bits in the RZ mode.

Transducer Materials

The two transducer materials presently used for digital delay lines are quartz crystal and piezoelectric ceramics, such as barium titanate and lead zirconate titanate. The quartz crystal is a low efficiency device having a coupling coefficient of only 0.14. The ceramic material has a coupling coefficient as high as 0.7. However, the ceramics have extraordinarily high dielectric

constants, and when used as transducers, have capacitances in the thousands of picofarads. In addition, the radiation resistances, which appear in parallel to the capacitances, run from a few ohms to 30 ohms. This combination may result in a transducer which is difficult to drive. Techniques are, however, available to reduce capacitances and increase radiation resistance to some degree. Values of capacitance and radiation resistance of quartz transducers run 50 to 150 pf and 5000 Ω to 1000 Ω .

General Characteristics of Digital Solid Delay Lines

Patterns

Solid delay lines are generally made from plates of glass which are about $\frac{1}{4}$ " thick. The reciprocal of the velocity of sound in fused quartz is 6.75 μ sec/in. and in zero T/C glass is 10 μ sec/inch. Thus, lines of any appreciable length must be made in patterns as shown below rather than rod form.

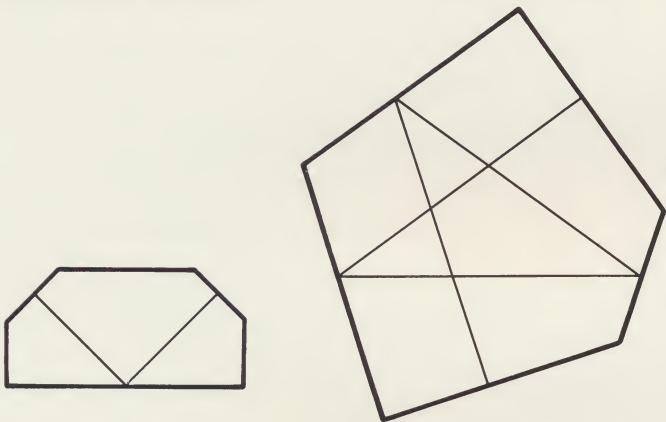


FIGURE 6
Typical Storage Patterns

Enclosures

The lines should be sealed in a metallic can or potted in a suitable epoxy. To avoid internal feedthrough, the transducers must have shields surrounding them. The higher frequency lines are generally placed in hermetically sealed metal containers in order that a ground plane completely surrounds the line protecting adjacent circuitry from the radiating transducers.

Temperature Control

Fused quartz lines are often heated in order to stabilize the time delay. The package for a heated line will, of course, be larger than that for an unheated line because of the insulation required to keep outward heat flow to a reasonable level. Temperature control is usually obtained by means of inexpensive solid state

controllers. Temperature control to $\pm \frac{1}{4}$ bit is readily obtainable. Where fast warm-up is needed, a warm-up heater, controlled by a snap action thermostat is added.

Representative Delay Line Sizes

Table I

Bit Storage	Delay Line Case Size, Inches
10	1 x $\frac{1}{2}$ x $\frac{1}{2}$
100	2 x 3 x $\frac{5}{8}$
1000	3 x 5 x $\frac{5}{8}$
10,000	10 x 10 x $1\frac{1}{2}$

Loss Characteristics

If quartz transducers are used, the voltage attenuation of a digital delay line will be in the neighborhood of 40 to 70 db. The factors which affect attenuation are: loss in the delay medium, transducer capacitance, transducer frequency and terminal resistance. For comparable storage, fused quartz lines exhibit less loss than zero T/C lines. A high capacitance results from a transducer with a large driving area, which maximizes the output signal. The efficiency of a transducer varies as the square of the frequency. However, the low loss of a high-frequency transducer is often offset by increased glass loss at high frequencies. The output of a quartz transducer operates as a constant current source if operated into a terminal resistance such as 50 Ω . Thus, if the output resistance is doubled, the voltage output is doubled.

The ceramic transducer line usually has a loss between 20 and 40 db. Because the transducer radiation resistance is low, the transducer is not a constant current source. The loss of the transducers at any frequency is so low that little can be gained by attempting to reduce it.

Signal-to-Noise Ratio

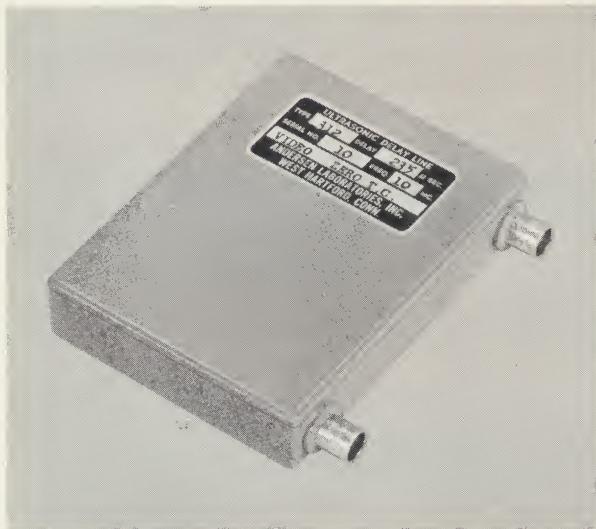
The signal-to-noise ratio of a digital line is determined by pulse distortion (previously discussed), spurious, and 3rd time signal. Except for low frequency lines, spurious signals in digital lines can be held to 30db below the output signal. However, if the bit packing density is high, these signals can add vectorially and contribute to noise. In short lines the signal which reflects from the output transducer and then from the input signal and appears as a spurious as the output, can be fairly strong. However, for a properly designed

transducer, this signal can be held to 40 db below the desired signal.

Prices of Digital Lines

Since a digital line stores a large number of bits in a single passive unit, the cost per bit is low. If the lines are used in large quantities and designed for economical storage, prices run between .5 to 2.5¢ per bit. Even in small quantities, prices generally do not run more than 10¢ per bit. Quotations are supplied based on quantities required, and types selected.

Manufacturers of Electronic Components and Systems



Typical Digital Delay Line

Delay Lines

- Fixed Ultrasonic
- Variable Ultrasonic
- Magnetostrictive
- Lumped Constant
- Distributed Constant

Electronics

- IF Amplifiers
- Modulators
- Servo Amplifiers
- Proportional Temperature Controllers
- Recirculation Loops

Systems

- Ultrasonic Decade Systems
- Target Simulator Equipment
- Pulse Compression Equipment
- Parallax Correction Equipment
- Weapon Fire Control Equipment



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WEST HARTFORD, CONN.

Represented by:

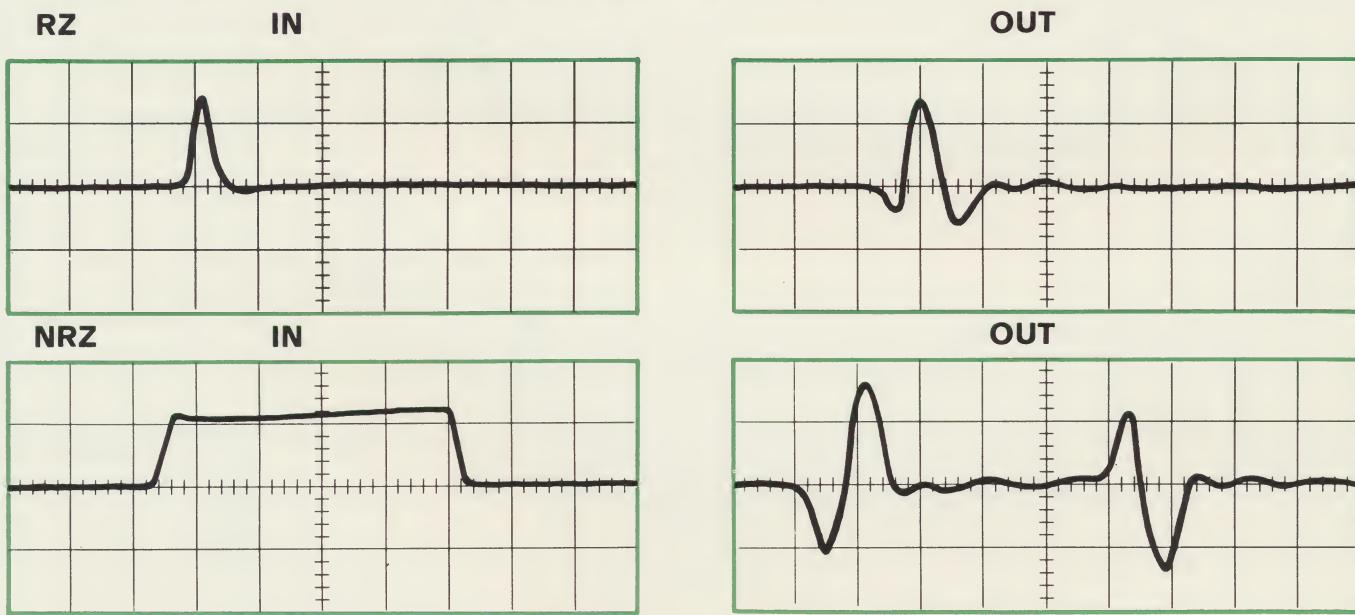
Digital Delay Line Type 1452 175-20

Applications:

Due to its high storage capacity and dual channel capability, this line finds its major use as a main memory unit.

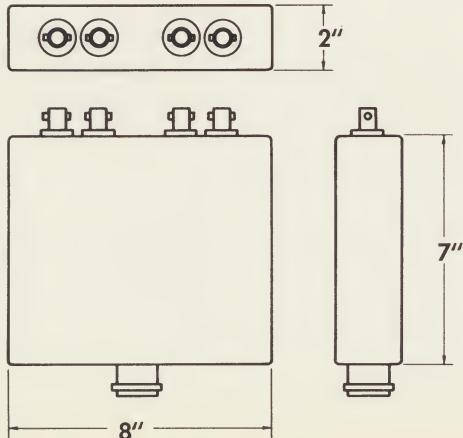
Delay Time	175 μ sec
Number of Channels	1 or 2
Delay Time Tolerance	± 10 nsec
Delay Stability	$\pm \frac{1}{4}$ bit, temperature controlled
Recommended Bit Length	20 nsec
Maximum Data Rate RZ	20 mc
Voltage Attenuation	60 db/93 Ω
Individual Spurious	30 db
Third Time	30 db
Signal to Noise Ratio	20 db
Terminal Capacitance	60 ± 10 pf

Typical Pulse Performance



SWEEPSPEED—40 nsec/cm

DIMENSIONS:



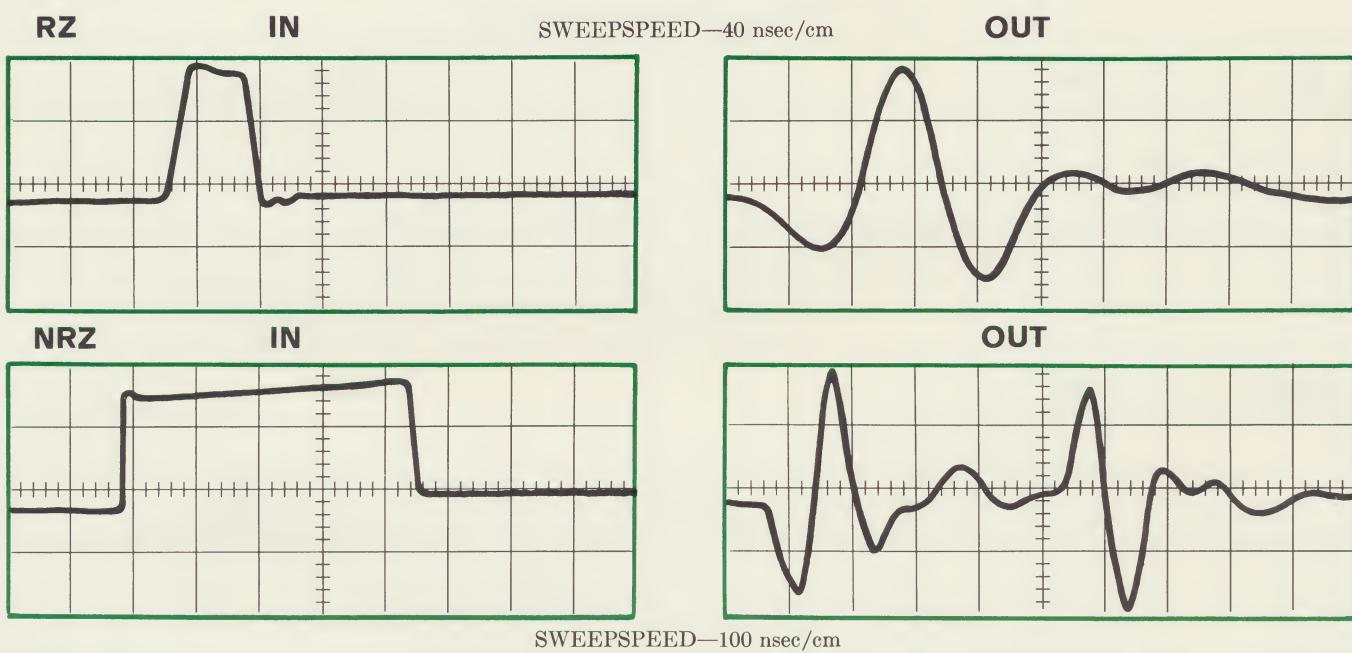
Digital Delay Line Type 1503 10-10

Applications:

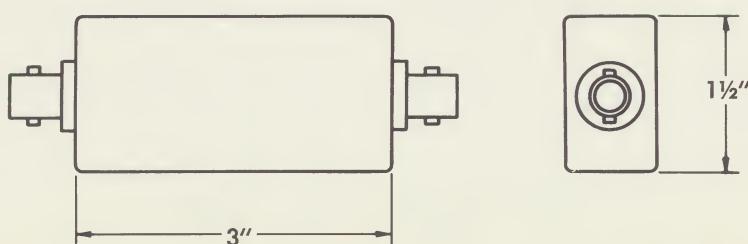
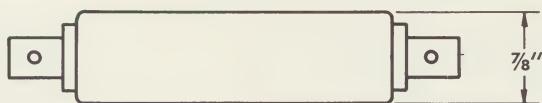
The ceramic transducers on this device produce a delay line with low insertion loss. This line finds use as a scratch pad memory.

Delay Time	10 μ sec
Delay Time Tolerance	± 10 nsec
Delay Stability	-75 ppm/ $^{\circ}$ C
Recommended Bit Length	40 nsec
Maximum Data Rate RZ	10 mc
Voltage Attenuation	29 db/93 Ω
Individual Spurious	40 db
Third Time	35 db
Signal to Noise Ratio	15 db
Terminal Capacitance	2000 ± 200 pf
Radiation Resistance	4 Ω

Typical Pulse Performance



DIMENSIONS:



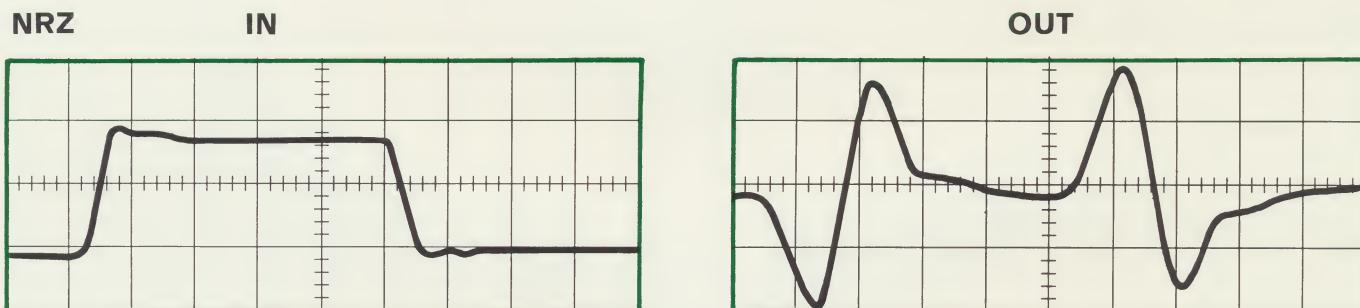
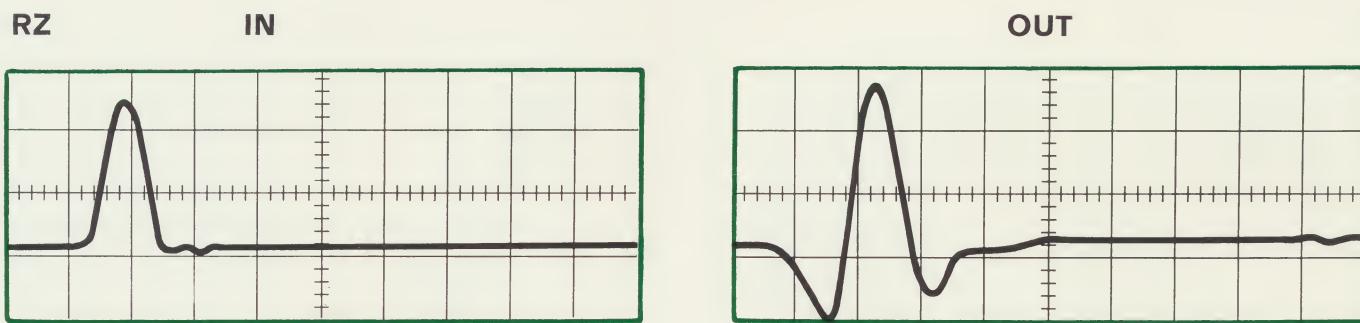
Digital Delay Line Type 1415 1-20

Applications:

This line is useful for high speed buffer memory applications. It is often used as a one word memory.

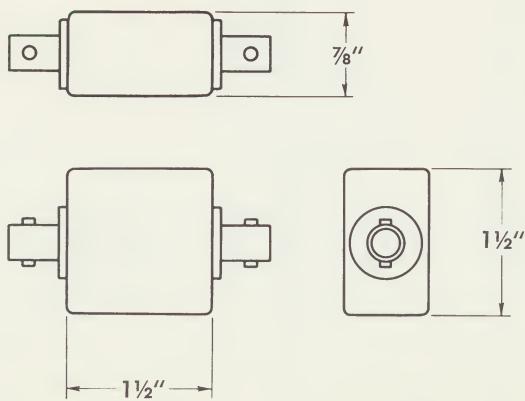
Delay Time	1 μ sec
Delay Time Tolerance	\pm 10 nsec
Delay Stability	\pm 2 ppm/ $^{\circ}$ C
Recommended Bit Length	20 nsec
Maximum Data Rate RZ	20 mc
Voltage Attenuation	50 db/93 Ω max
Third Time Signal	30 db
Signal to Noise Ratio	15 db
Terminal Capacitance	85 \pm 10 pf

Typical Pulse Performance



SWEEPSPEED—20 nsec/cm

DIMENSIONS:



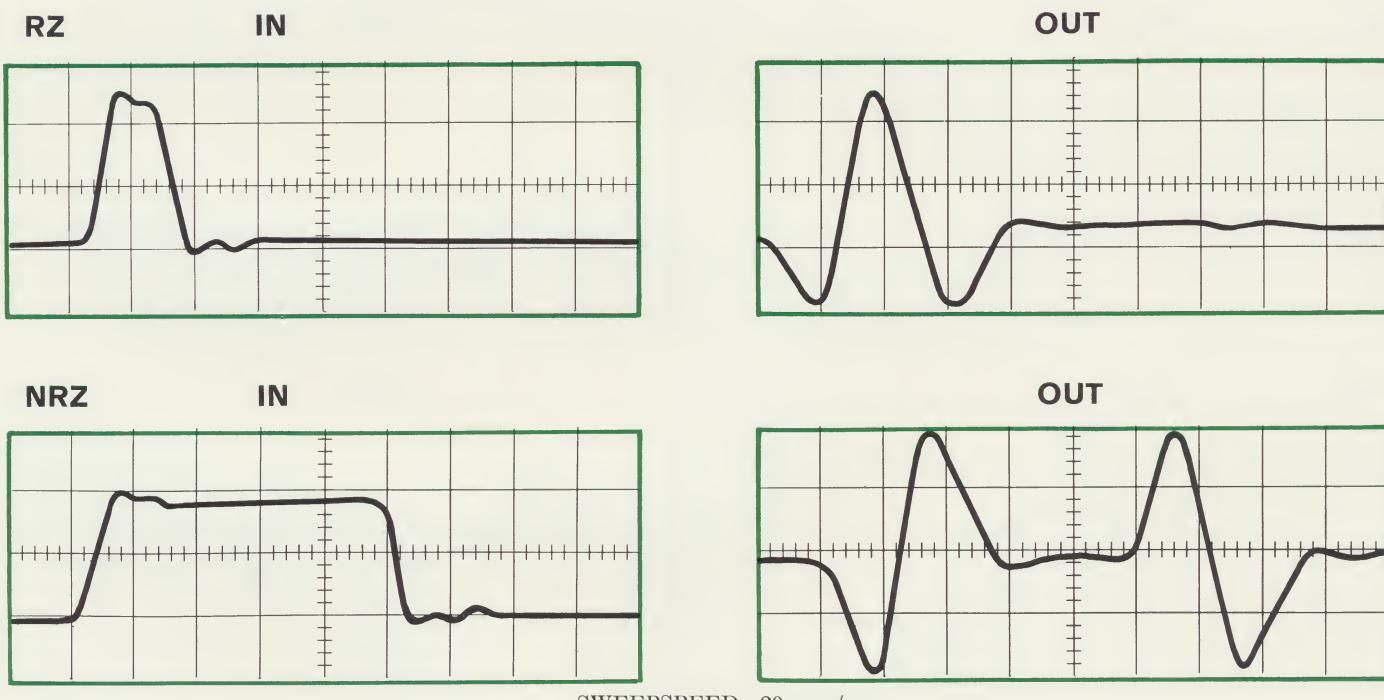
Digital Delay Line Type 1500 5.5-20

Applications:

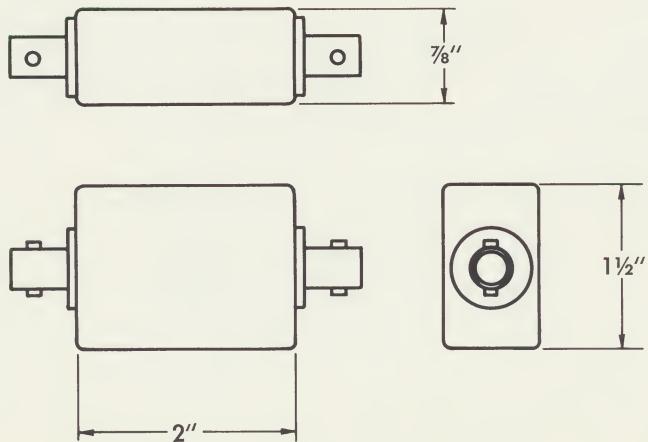
The primary application for this line is high speed buffering of several words.

Delay Time	5.5 μ sec
Delay Time Tolerance	± 10 nsec
Delay Stability	± 2 ppm/ $^{\circ}$ C
Recommended Bit Length	20 nsec
Maximum Data Rate RZ	20 mc
Voltage Attenuation	50 db/93 Ω
Third Time Signal	40 db
Signal to Noise Ratio	15 db
Terminal Capacitance	85 \pm 10 pf

Typical Pulse Performance



DIMENSIONS:



ELECTROMAGNETIC DELAY LINES

Long acknowledged as the leader in the design, engineering, and manufacture of quartz ultrasonic delay lines, Andersen Laboratories is now offering — through its Wirewound Division — lumped-constant and distributed-constant delay lines to meet the most stringent requirements. Custom-designed for a variety of applications in radar, sonar, telemetry, computers, missiles, data processing, geophysical exploration, nuclear research, instrumentation, etc., these delay lines are produced to the most exacting standards of workmanship, performance, and reliability.

Andersen Electromagnetic Delay Lines Feature:

- High component density (up to 70 delay sections per cubic inch)
- High delay density (up to 500 μ sec per cubic inch)
- High delay-to-rise-time ratios (up to 150/1)
- Wide delay range (nanoseconds to milliseconds)
- Wide impedance range (10 ohms to 10,000 ohms)
- Extended temperature range (up to 250° C.)
- Extreme thermal stability (as low as 10 ppm/°C.)
- Low attenuation
- Wide choice of mechanical characteristics and configurations



DEFINITIONS OF CHARACTERISTICS

DELAY TIME — T_d

The elapsed time between the 50% amplitude points on the leading edges of the delay line input and output pulses.

CHARACTERISTIC IMPEDANCE — Z_c

The value of terminating impedance which provides minimum reflections at the input of the delay line.

RISE TIME — t_r

The elapsed time between the 10% and 90% amplitude points on the leading edge of the pulse.

Delay Line Rise Time — t_r

The output rise time assuming a step function input.

ATTENUATION — α

The difference in voltage amplitude between delay line input and output pulses, compared to the input pulse amplitude. Expressed in % or db. as follows:

$$\alpha (\%) = \frac{E_i - E_n}{E_i} \times 100$$

$$\alpha (\text{db}) = 20 \log_{10} \frac{E_i}{E_n}$$

DISTORTION — B,C,D, and S

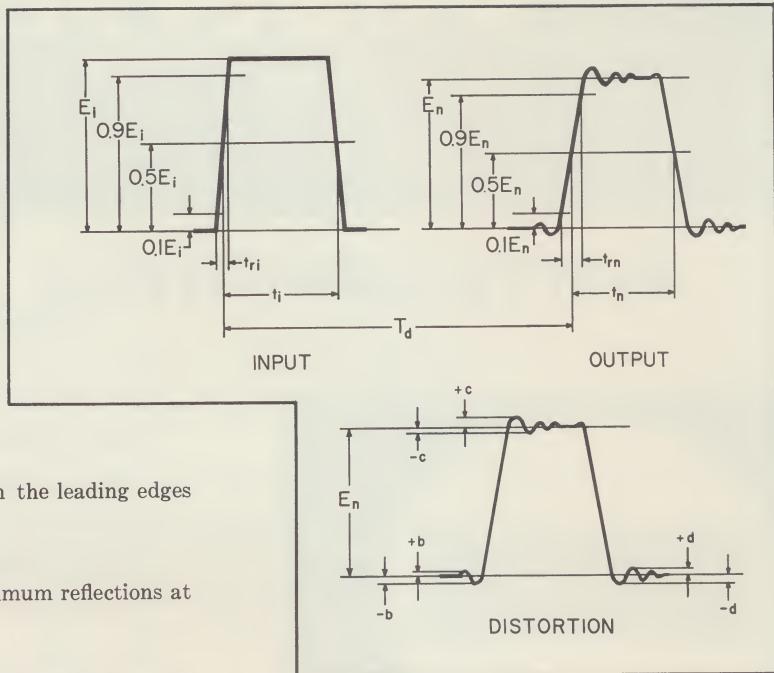
Defined in percent by indicating the value of b, c, or d relative to the pulse amplitude. S is an all encompassing figure defining the largest value of b, c, or d relative to the pulse amplitude.

$$\pm B = \frac{\pm b}{E_n} \times 100$$

$$\pm C = \frac{\pm c}{E_n} \times 100$$

$$\pm D = \frac{\pm d}{E_n} \times 100$$

$$\pm S = \pm \frac{|b| \text{ or } |c| \text{ or } |d|}{E_n} \times 100$$



PULSE DURATION — t_n

The elapsed time between the 50% amplitude points of the leading and trailing edges of the pulse.

Wherever applicable, the above definitions refer to either the input or any output pulse. The general subscript "n" is used to identify the pulse at any point, n. The specific subscripts "i", "o", and "v" apply to input, end-of-delay line output, and variable output, respectively.

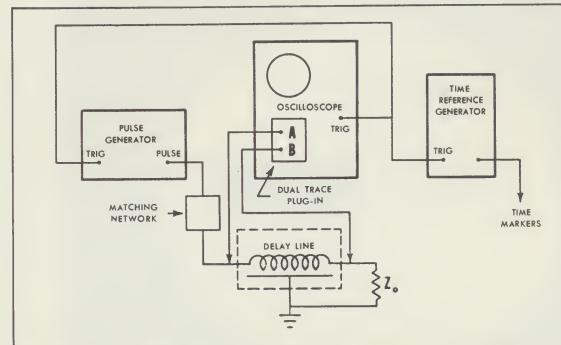
These definitions are intended to conform to *EIA Standards on Definitions for Electromagnetic Delay Lines*. Although the customer is not bound to these definitions, it is best to comply with them in the interest of better consistency throughout the industry. Unless specifically stated otherwise, all specifications will be assumed to be in accordance with these definitions.

MEASUREMENTS

A basic delay line measurement circuit is shown on the right.

The time markers may be used as accurate reference points by feeding them into one of the vertical amplifier channels or into the Z-axis modulation terminals. Using either method the time markers can be displayed simultaneously with the delay line pulses.

If a delay line must be tested by a different or more specific test method, that method and test circuit should be fully described.



ANDERSEN LABORATORIES STANDARD LUMPED-CONSTANT DELAY LINES

Delay Tolerance: $\pm 5\%$

Attenuation: 1 μ sec and below: 1 db max.
 1 μ sec — 10 μ sec: 3 db max.
 10 μ sec — 25 μ sec 5 db max.

Temperature Coefficient of Delay: 50 ppm/ $^{\circ}$ C. max.

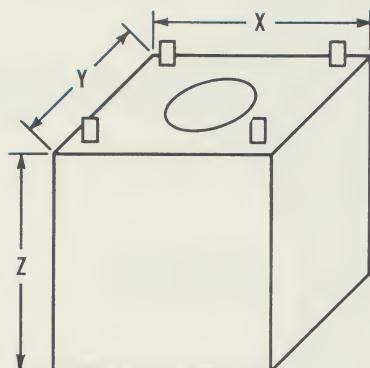
Operating Temperature Range: -55° C. to 125° C.

Construction: Hermetically sealed in steel case

Finish: Grey lacquer over hot tin dip or copper plate

ANDERSEN STANDARD LUMPED CONSTANT DELAY LINES

DELAY TIME	RISE TIME	CASE SIZE	CHARACTERISTIC IMPEDANCE		
			100 Ω	500 Ω	1000 Ω
.25 μ sec	.015 μ sec	A	0100-0.25-.015	0500-0.25-.015	1000-0.25-.015
	.025 μ sec	A	0100-0.25-.025	0500-0.25-.025	1000-0.25-.025
.50 μ sec	.03 μ sec	A	0100-0.50-0.03	0500-0.50-0.03	1000-0.50-0.03
	.05 μ sec	A	0100-0.50-0.05	0500-0.50-0.05	1000-0.50-0.05
1.0 μ sec	.03 μ sec	B	0100-1.00-0.03	0500-1.00-0.03	1000-1.00-0.03
	.05 μ sec	A	0100-1.00-0.05	0500-1.00-0.05	1000-1.00-0.05
	.10 μ sec	A	0100-1.00-0.10	0500-1.00-0.10	1000-1.00-0.10
1.45 μ sec	.05 μ sec	C	0100-1.45-0.05	0500-1.45-0.05	1000-1.45-0.05
	.075 μ sec	B	0100-1.45-0.075	0500-1.45-0.075	1000-1.45-0.075
	.1 μ sec	A	0100-1.45-0.10	0500-1.45-0.10	1000-1.45-0.10
5.0 μ sec	.15 μ sec	C	0100-5.00-0.15	0500-5.00-0.15	1000-5.00-0.15
	.25 μ sec	B	0100-5.00-0.25	0500-5.00-0.25	1000-5.00-0.25
	.50 μ sec	A	0100-5.00-0.50	0500-5.00-0.50	1000-5.00-0.50
10.0 μ sec	.30 μ sec	C	0100-10.0-0.30	0500-10.0-0.30	1000-10.0-0.30
	.50 μ sec	C	0100-10.0-0.50	0500-10.0-0.50	1000-10.0-0.50
	1.0 μ sec	B	0100-10.0-1.00	0500-10.0-1.00	1000-10.0-1.00
20.3 μ sec	.5 μ sec	D	0100-20.3-0.50	0500-20.3-0.50	1000-20.3-0.50
25.0 μ sec	.5 μ sec	D	0100-25.0-0.50	0500-25.0-0.50	1000-25.0-0.50
	1.0 μ sec	C	0100-25.0-1.00	0500-25.0-1.00	1000-25.0-1.00
	2.5 μ sec	B	0100-25.0-2.50	0500-25.0-2.50	1000-25.0-2.50



Case Letter	X	Y	Z	# Studs
A	1 1/2"	1 1/2"	3"	2
B	2"	2"	4"	4
C	2"	4"	4"	4
D	4"	4"	4"	4

REPRESENTATIVE DESIGNS



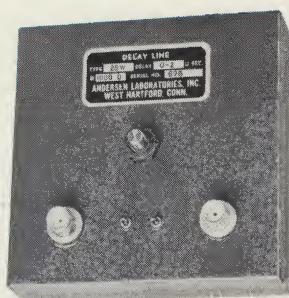
PRECISION AUDIO DELAY NETWORKS

FEATURES

Excellent phase linearity • wide bandwidth • low attenuation • extreme temperature stability

SPECIFICATIONS

Delays: from 100 μ sec to beyond 300 msec
Impedances: from 50 to 5000 ohms
Operating voltages: up to 600 volts
Tapped, balanced or unbalanced versions available.



STEP VARIABLE DELAY LINES

FEATURES

High delay/rise time ratios • wide impedance range
High pulse fidelity • hermetically sealed • with or without detent • motor driven operation possible

TYPICAL SPECIFICATIONS

Delay: 0–2 μ sec, in 52 steps
Impedance: 1000 ohms
Rise time: 0.1 μ sec max.
Attenuation: 2dB max.
Size: $4\frac{1}{2} \times 4\frac{1}{2} \times 1\frac{1}{8}$



CONTINUOUSLY VARIABLE DELAY LINES

FEATURES

High resolution • low temperature coefficient • long contact life • excellent mechanical stability • printed circuit mounting

TYPICAL SPECIFICATIONS

Delay: 0–0.5 μ sec
Resolution: better than 0.01 μ sec
Impedance: 1000 ohms
Rise time: 0.08 μ sec max.
Attenuation: 1 dB max.
Size: $4\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{2}$



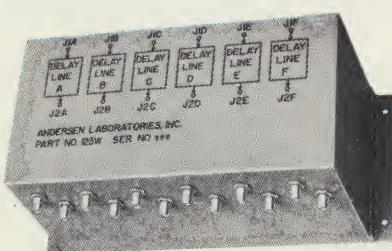
COMPUTER DELAY LINES

FEATURES

Reliability at low cost • epoxy encapsulation • rapid and consistent production • printed circuit mounting

TYPICAL SPECIFICATIONS

Delay: 1 μ sec with taps every .1 μ sec
Impedance: 1500 ohms
Rise time: 0.075 μ sec max.
Attenuation: 1 dB max.
Size: $6 \times 1\frac{1}{2} \times \frac{5}{8}$



PRECISION FIXED DELAY LINES

FEATURES

Hermetic sealing • conformance to military specifications • High reliability • High delay/rise time ratios • Low distortion

TYPICAL SPECIFICATIONS

Delay: 20.3 μ sec
Impedance: 220 ohms
Rise time: 0.2 μ sec max.
Attenuation: 1.7 dB
Spurious Signals: 4% max.
Size: $8 \times 4 \times 3$



NEW!

FROM
ANDERSEN
LABORATORIES

ELECTRICALLY VARIABLE DELAY LINES

The delay line is composed of series connected inductors, with shunt capacitors (typical L-C network). There are three methods by which Electrical Variation in Delay is achieved:

- 1) The inductors have a second winding around them, which is then connected to an external current source. Increasing current through this control winding decreases the network's impedance and shortens the delay time.
- 2) The voltage variable capacitors have an external voltage bias supply connected across them. Increasing this voltage increases the network's impedance and shortens the delay time.
- 3) Using voltage variable capacitors and current variable inductors, increasing both voltage and current simultaneously will permit the delay line to be shortened at approximately constant impedance. The effect is non-linear, however, requiring compensation in the control circuitry if linearity is a requirement. We shall be glad to furnish circuit suggestions to accomplish this linearity, if they should be needed or desired by users.

The current supply requirement is typically up to 400 milliamperes at a low voltage, depending on delay line design. The voltage supply is typically 0 to 70 volts with a current requirement in the low microampere range.

Using either the current or voltage supply independently, the delay time can be reduced to about 40% of the unit's nominal delay. If both supplies are used, the delay time can be reduced to about 15% of nominal delay, or a 7:1 ratio. The current bias may be in either direction, but the voltage bias must be positive with respect to ground. For minimum distortion, the input signal should be less than one volt, peak to peak.



Electrically Variable Delay Line, an Andersen product offering a unique approach to pulse positioning and phase control, features the advantage of controlling delay by electrical rather than mechanical means. This device effects variation in delay through the application of direct current and voltage bias on a control winding. In addition to these static control techniques, alternating currents up to 100 kc may also be used to achieve dynamic control or modulation.

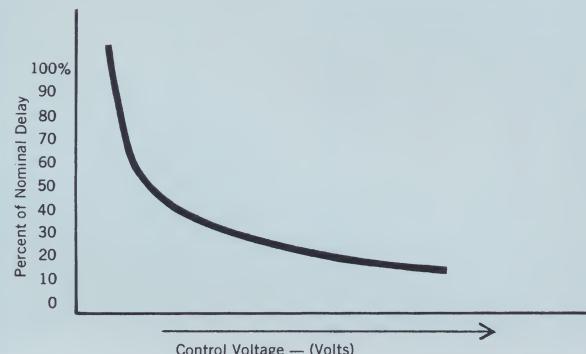
Electrically Variable Delay Lines provide a new method for the solution of problems in transmission time control, pulse control and shaping, high frequency phase control, pulse time modulation, and phase or frequency modulation.

Designed and built for either carrier or pulse type applications, these Electrically Variable Delay Lines can be produced within a wide range of operating characteristics. They are highly adaptable to transistorized circuitry and will withstand extreme humidity, shock, and vibration.

Inquiries are invited regarding delay lines for specific application, tailored to customer's needs in such equipment as radar, computers, and mobile communications.

TYPICAL CURRENT/VOLTAGE CURVES

Delay variation requires two separate sources; one current source (upper curve) and/or one voltage source (bottom curve). Both are low power circuits. We will supply associated modulation circuitry.



GENERAL SPECIFICATIONS

Delay-Bandwidth Product 20 mc μ sec. Max.
Maximum/Minimum Delay Ratio 7:1 Max.
Delay-to-Rise Time Ratio 50:1 Max.
Characteristic Impedance any value from 50 to 5,000 ohms.
Some restrictions when operating at extreme range of other specifications.

Andersen Laboratories offers the most complete variety of delay lines in the industry. In addition to the lines described here, the Company has long been the leading producer of solid ultrasonic delay line systems, as well as digital glass, wiresonic, and lumped-constant delay lines. For information on the above, as well as Electrically Variable Delay Lines as described, or standard electromagnetic lines, contact the nearest Andersen Laboratories Representative, or the Home Offices for a prompt response.



**ANDERSEN
LABORATORIES**

501 NEW PARK AVENUE

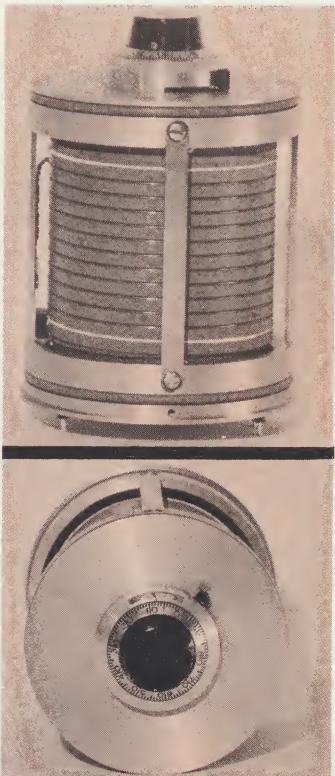
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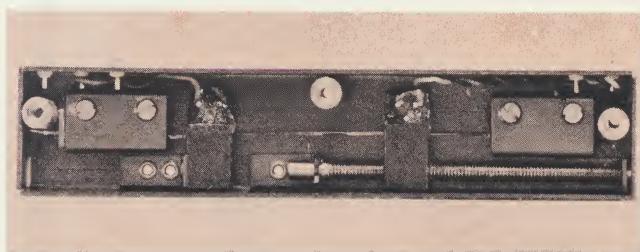
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MAGNETOSTRICTIVE DELAY LINES

*Continuously
 variable
 longitudinal*

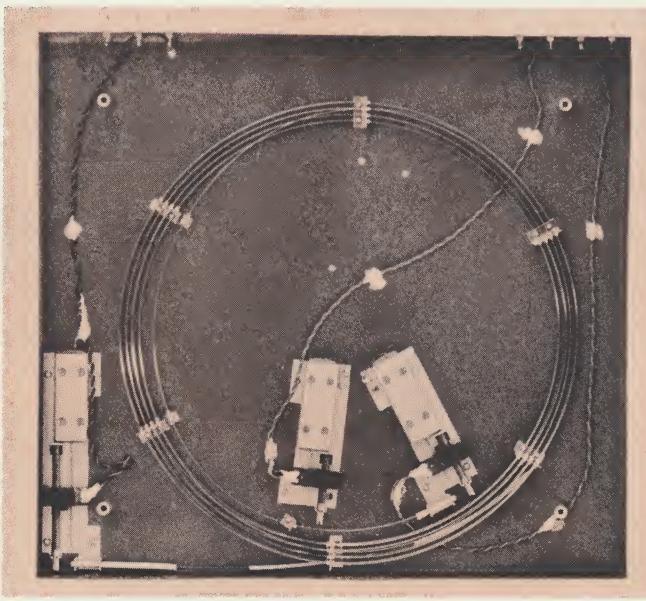


*Fixed or
 variable
 longitudinal*



ANDERSEN MAGNETOSTRICTIVE DELAY LINES FEATURE:

- Standard Package Designs
- Printed Circuit Electronics
- Large Storage Capacity
- Low Temperature Coefficients
- Wide Range of Options Available
- Low Cost per Bit
- Fast Delivery
- High Repetition Rates
- Excellent Signal-to-Noise Ratios
- Highest Quality Workmanship



Torsional

Andersen Laboratories, a pioneer in delay line design and development since 1949, offers the industry's widest range of high-performance magnetostrictive delay lines and associated circuitry. Designs for both military and commercial applications are available. Field data from many production runs underlie Andersen's guarantee of reliability and performance.

Andersen's work in magnetostrictive delay lines can be divided into two categories: custom manufacturing and standard catalog manufacturing. In the custom category, Andersen's design engineers assist in drafting the specification, advise on state-of-the-art considerations and recommend manufacturing economies. Andersen then manufactures the device in accordance with the resulting drawings. Andersen has performed in custom manufacturing contracts for many defense producers, building fully militarized devices and performing appropriate qualification tests.

The Andersen standard catalog line of magnetostrictive delay lines is summarized in this brochure and further detailed in individual data sheets. A wide range of options is also available in the standard line. Andersen is fully tooled on all catalog units with preassemblies, cases, printed circuit boards, etc., available from stock. For this reason, deliveries on most standard lines can be made in one week.

Magnetostrictive Delay Lines – General Information

What are magnetostrictive delay lines?

Magnetostrictive delay lines convert electronic pulses or signals (which normally travel at the speed of light) to ultrasonic pulses (which travel at the speed of sound) for the purpose of storing digital information for a predetermined period of time.

Where are they used?

Magnetostrictive delay lines are used extensively in computer data storage systems, radar and sonar systems, radar target simulators, telemetry and navigational equipment, signal expanders, and compressors, data processing equipment, digital accumulators, memory buffers, shift registers, counters, nuclear research and in many kinds of instrumentation.

What are some important physical properties?

These are the properties of magnetostrictive delay lines that account in part for their growing popularity: inherent temperature stability, no moving parts, high reliability, ruggedness, compact size and relatively low cost.

How does a magnetostrictive delay line work?

Magnetostrictive delay line performance is deter-

mined by the combined effects of three phenomena:

1. The magnetostrictive or Joule Effect. When a magnetostrictive material is subjected to a magnetic field parallel to its length, it changes shape. Positive magnetostriction results in expansion of the material, negative magnetostriction in contraction. Nickel, for example, has negative magnetostriction.
2. The propagation of sonic energy in an elastic material. When the magnetostrictive material changes length, it launches rarefactive or compressive waves. These waves travel at sonic velocities — approximately 0.2 inches per microsecond, or at the rate 5 microseconds per inch of delay medium.
3. Inverse magnetostriction, or the Villari effect. When a magnetostrictive material is subjected to a mechanical strain while at the same time it is biased by a magnetic field, a change in flux density within the material generates an emf. This emf is a voltage pulse with a positive and a negative peak.

When the current to the biasing magnet is cut off, the magnetic field collapses, the magnetostrictive material returns to its original length, a compressive wave travels down the length of the material to the output coil, and another emf (opposite in polarity to the original) is generated.

Standard Delay Lines

	MODEL NO.	DIMENSIONS	DELAY RANGE, USECS.
TORSIONAL	WS-110	15 $\frac{3}{4}$ x 14 $\frac{1}{4}$ x 1	8000 to 16,000
	WS-100	11 x 12 $\frac{1}{4}$ x 1	4000 to 10,000
	WS-90	11 x 12 $\frac{1}{4}$ x $\frac{1}{2}$	2000 to 5000
	WS-80	8 x 9 $\frac{1}{4}$ x 1	2400 to 5000
	WS-70	8 x 9 $\frac{1}{4}$ x $\frac{1}{2}$	1800 to 2500
	WS-60	5 x 6 $\frac{1}{4}$ x 1	800 to 2000
	WS-50	5 x 6 $\frac{1}{4}$ x $\frac{1}{2}$	250 to 1000
	WS-40	4 x 5 $\frac{1}{4}$ x $\frac{1}{2}$	50 to 275
LONGITUDINAL*	WS-30	25 $\frac{1}{2}$ x 1 $\frac{1}{2}$ x $\frac{1}{2}$	30 to 100
	WS-20	13 $\frac{1}{2}$ x 1 $\frac{1}{2}$ x $\frac{1}{2}$	10 to 40
	WS-10	8 $\frac{1}{2}$ x 1 $\frac{1}{2}$ x $\frac{1}{2}$	5 to 15
CONTINUOUSLY VARIABLE	M-3	4" dia. x 6" long	3 to 500

*All longitudinal delay lines can be continuously variable from 2 usecs. to the maximum delay indicated.

Andersen Laboratories Magnetostriuctive Delay Lines

Condensed Catalog

CHARACTERISTIC	DEFINITION†	STANDARD RANGE	AVAILABLE ON SPECIAL ORDER
Delay, usecs.	The time required for a signal to traverse the delay medium, from input to output, measured between the 50% point of the input current step and the zero crossing of the output doublet.	2 to 10,000	as high as 16,000
Pulse repetition rate (PRR), or digit rate, mc max.	The maximum repetition rate (or two times the pulse width) at which the line can be used in a return-to-zero (RZ) mode. For the non-return-to-zero (NRZ) mode, the PRR is doubled.	.25 to 1.0 RZ .5 to 2.0 NRZ	4 mc NRZ
Input pulse width, usecs.	The width of the pulse measured at the 50% amplitude points, as it appears at the input terminals of the delay line.	.25 to 2.0	.1 to 4.0
Storage capacity, bits per package, max.	The product of the delay and the PRR.	10,000	16,000
Temperature coefficient, PPM/ $^{\circ}$ C.	The change in delay time in parts per million per $^{\circ}$ C.	1.0 to 10.0 (may be higher, depending upon propagation mode)	as low as 0.25
Delay adjustment, usecs.	Variable adjustment, increase or decrease.	2 to 20*	as much as 40
Single pulse signal-to-noise ratio, (S/N), min.	The ratio of desired output peak pulse amplitude from the base line to its major lobe, to the peak noise value of any other voltage, also measured from base line to peak. Noise is due to line reflections and stray couplings.	20:1	as high as 50:1
Driving impedance, ohms.	The driving source impedance, or the output impedance of the device driving the delay line.	50 to 500	as high as 2000
Output termination, ohms.	The resistive and capacitive value which will terminate the delay line.	500 to 4000	as high as 10,000
Input current, millamps.	The drive current through the input network.	25 to 100	
Attenuation or insertion loss, db.	The ratio of the input voltage to the output voltage.	approx. 60	as low as 40
Output voltage, millivolts.	As measured into the output termination.	5.0 min.	
Environmental characteristics.	Operating temperature and relative humidity ranges.	0 to 50 $^{\circ}$ C, 10 to 85% humidity	-55 to +100 $^{\circ}$ C, 0 to 100% humidity

*The range of adjustment on the continuously variable type magnetostriuctive lines is 3 to 500 usec.

†Andersen Laboratories uses the definitions and measurement standards as proposed by the Electronic Industries Association P.3.7.1 Committee.

Unity Gain Delay— Magnetostrictive Memory Units

Unity gain delay magnetostrictive memory units provide 20 to 2000 usec delays, with the reshaped output signal conforming to the input signal in both amplitude and pulse width. They may be used for random pulse delay or for storage of clocked pulses.

Andersen memory units are available in three standard case sizes, in hermetically-sealed and non-hermetically sealed packages. In the latter, all electronics are contained within the package.

Specifications:

2 MC line (RZ)

Frequency range: .25 to 2.0 mc

Input signal: 3.0 to 24 volts

Input impedance: 5000 ohms

Output impedance: 91 ohms

Output rise time: less than 0.1 clock period

Delay adjustment: \pm 2 usec

Time delay stability: $\frac{1}{2}$ ppm/ $^{\circ}$ C

Power supply: \pm 12 volts

Storage capacity: 20 to 4000 bits RZ.

Magnetostrictive Recirculating Serial Memory Systems

Andersen Laboratories serial memory systems are composed of one or more units gain delays, with reclocking inputs available between stages. Gating inputs are also available for read-in and erase functions. Up to 4000 bits may be stored per unit, and cascading of stages provides unlimited storage capacity. Each memory system is a self-contained, rack-mounting unit, with power supply available. Andersen Laboratories, Inc., reserves the right to make changes in these specifications without notice as part of our continuing program of product improvement.

1-2-3 Ordering Information

When ordering, be sure to include the following information: (1) model number; (2) delay time; (3) electrical characteristics from page 2.

Note: If electrical characteristics are not stated, the following characteristics will be supplied: 300 ohms driving impedance, 2000 ohms output termination, and a temperature coefficient of greater than 2 ppm/ $^{\circ}$ C.

All units can be provided with both read and write amplifiers and can be hermetically sealed. Mounting provisions include four 6-32 inserts or studs, according to the customer's requirements, with mounting from either side possible.

There Is an Andersen Representative Nearby

Arizona	Southwest Machine Corp. 222 North 7th Ave. P.O. Box 13626 Phoenix, Arizona	602 AL 4-4197
California	Sanders & Sanders 18406 Calvert St. Reseda, California	213 DI 3-9689
Kansas, Missouri	Impala Overland Park, Kansas St. Louis, Missouri	913 NI 8-6901 314 JA 2-1600
Maryland, Penna.	Burgin & Kreh Assocs. 107 York Road Towson 4, Maryland	301 VA 5-3212
Michigan	Hal Heym Associates 1688 Buckingham Rd. Birmingham, Michigan	313 MI 4-9166
New Jersey	Burgin & Kreh Assocs. Cherry Hill, N. J.	609 428-6868
New York (Upstate)	James L. Semple 21 Edgewater Lane Rochester 17, N. Y.	716 FI 2-1413
New York (Metropoli- tan N.Y.C., N.J. & L.I.)	Frank T. Battista Co. 223-46 Hempstead Ave. Queens Village 29, N.Y. 212 GR 9-3550	
Texas	Southern Eng'g & Sales 805 East Abram St. Arlington, Texas	817 CR 5-5441
Canada	Whittaker Electronics, Ltd. 2 Neapolitan Drive Scarboro, Ontario	AX 3-3161
Overseas	Dage Corporation 219 East 44 St. New York 17, N. Y.	212 MU 2-6755

andersen
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INCORPORATED

501 NEW PARK AVE. WEST HARTFORD, CONN.

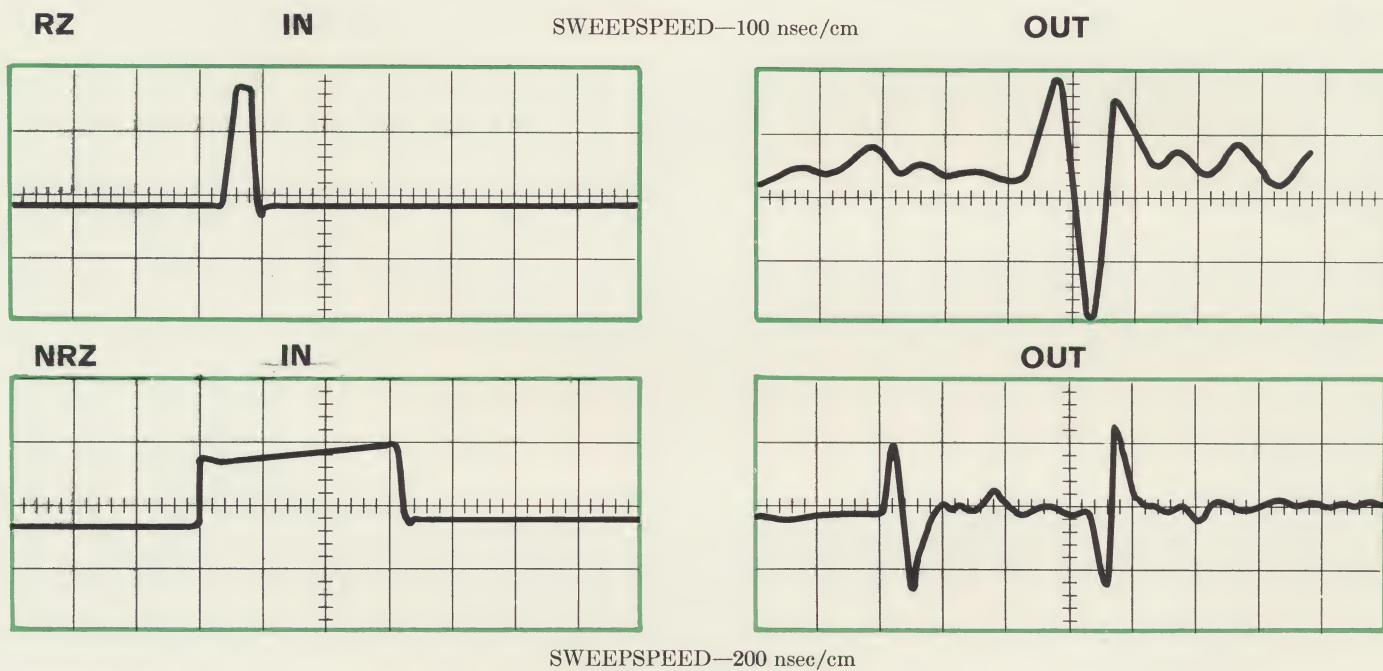
Digital Delay Line Type 1502 235-10

Applications:

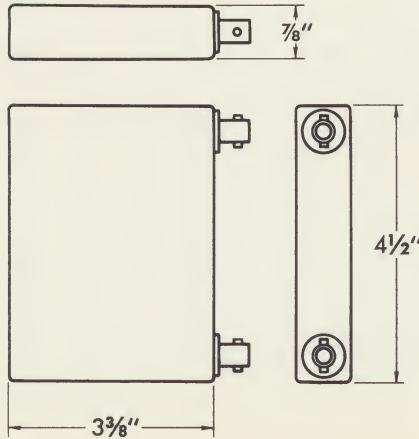
This line has a capacity of 2350 bits operating at 10Mc and can thus be used as a main or buffer memory storage unit. Its low T/C makes it useful over a wide temperature range. The line can serve as the memory for a Deltic correlator.

Delay time	235 μ sec
Delay Time Tolerance	± 10 nsec
Delay Stability, Rate of Change of T/C	+0.05 ppm/ $^{\circ}$ C ²
Zero Point of T/C	25 ± 10 $^{\circ}$ C
Recommended Bit Length	40 nsec
Maximum Data Rate RZ	10 mc
Voltage Attenuation	74 db/100 Ω
Individual Spurious	30 db
Third Time	50 db
Signal to Noise Ratio	15 db
Terminal Capacitance	40 ± 5 pf

Typical Pulse Performance



DIMENSIONS:



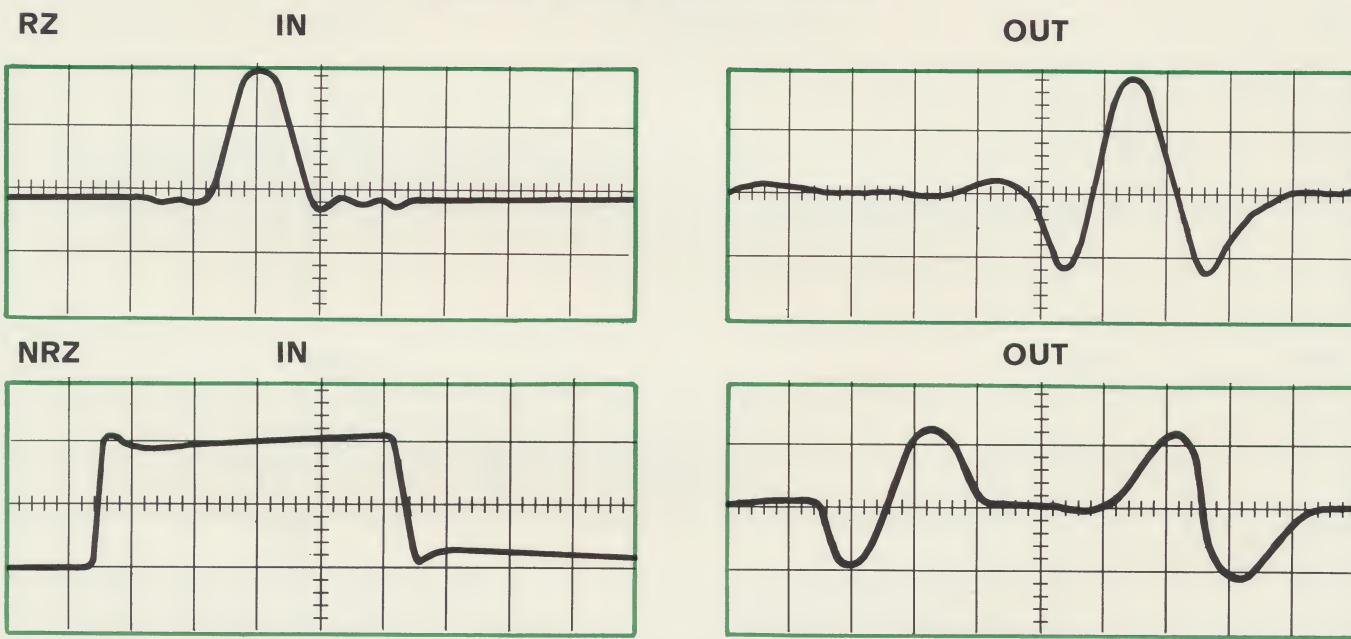
Digital Delay Line Type 1423 65-20

Applications:

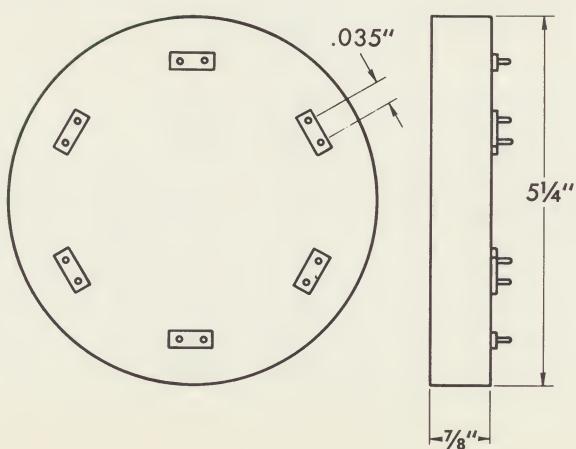
Because of its multiple channel characteristics, this line is extremely useful in systems which require multiple delays precisely matched across a wide temperature range.

Delay Time	65 μ sec
Number of Channels	1 to 3
Delay Time Tolerance, each channel	± 5 nsec
Delay Stability, Rate of Change of T/C	+0.05 ppm/ $^{\circ}$ C ²
Zero Point of T/C	25 ± 10 $^{\circ}$ C
Recommended Bit Length	20 nsec
Maximum Data Rate RZ	20 mc
Voltage Attenuation	58 db/75 Ω
Individual Spurious	40 db
Third Time	50 db
Signal to Noise Ratio	15 db
Terminal Capacitance	130 ± 10 pf

Typical Pulse Performance



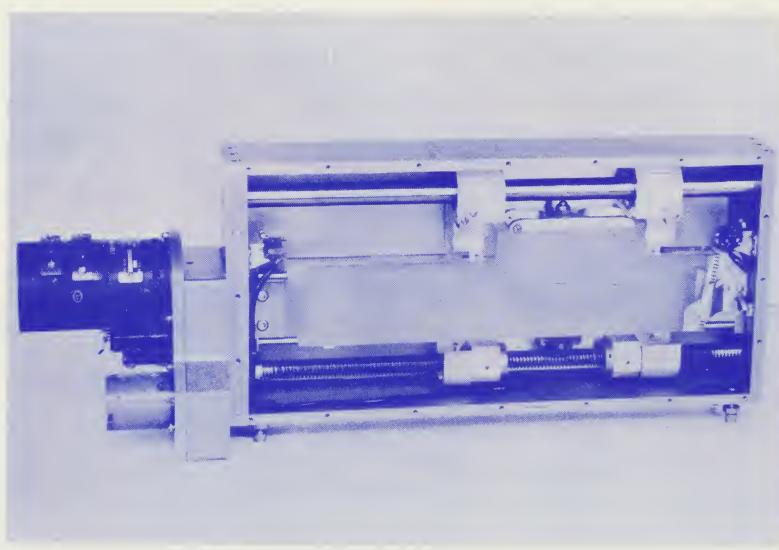
DIMENSIONS:



APPLICATIONS: TARGET SIMULATOR

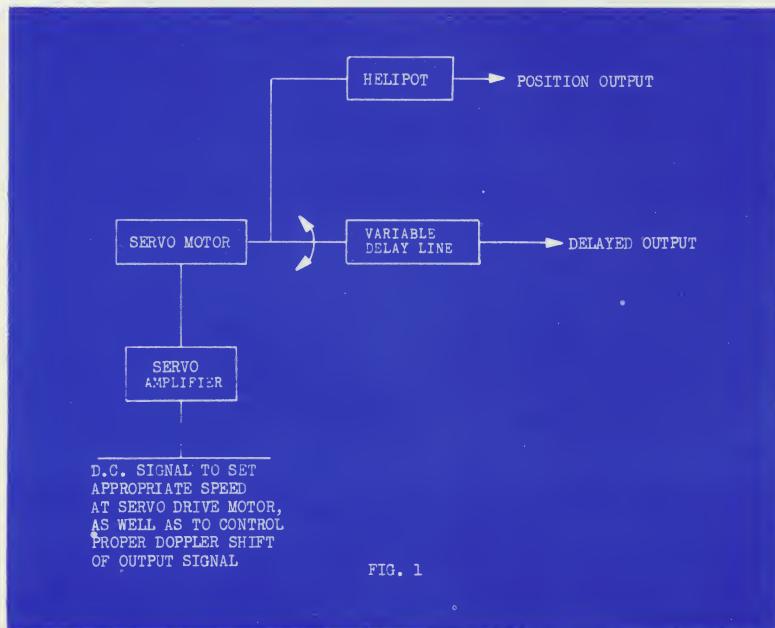
- Simulates rapidly moving targets to 20,000 ft/sec.
- Delay time range can be coupled with appropriate doppler shift to simulate actual velocities.
- Phase coherence of simulated target readily maintained.

A new application for Andersen Laboratories variable delay lines is the simulation of rapidly moving targets. Proper design can provide actual range at all times coupled with the appropriate doppler shift in frequency to simulate the precise movement of actual targets. With the variable delay line, guidance radars and fire control radars



can be conveniently checked for signal to noise ratio, range calibration, subclutter visibility and other specifications of operation both in production testing and at field sites.

While variable ultrasonic lines typically operate in the region of 30-40 MCPS, phase coherence of the simulated targets is readily maintained by well known techniques involving reciprocal double mixing. As seen in figure 1, a single command function causes the delay line to vary in length at the appropriate velocity and at the same time causes the doppler shift corresponding to this velocity to be made. The output of the position potentiometer is that of the instantaneous range. This device is especially useful in pulsed doppler systems but it is obviously applicable to testing other types of radars.



PRF ADJUSTMENT

- Slaves PRF to other radar.
- Provides remote adjustment of video integrator PRF to prevent interference.
- Provides variation at end of long delays.

The minimum delay of Andersen Laboratories variable delay lines can be as long as any fixed line. For example, with a nominal delay of approximately 2778 μ sec an adjustable range is provided, such that

COMMUNICATIONS and COUNTER MEASURES APPLICATIONS

- Measures time differentials to .010 μ sec.
- Relative delays from zero μ sec obtainable.
- Infinite resolution.

Andersen Laboratories variable delay lines have infinite resolution, and because of the extreme pre-

a continuous variation from 2768 μ sec to 2788 μ sec is obtained. The resolution over this range is infinite and the variation is readily servo controlled.

These lines are invaluable in various radar applications, such as Beacon Defruiters, where it is necessary to slave the system p.r.f. to that of some existing radar.

In addition long lines with variations are extremely valuable in video integrators. By changing the delay slightly, either by means of a manual or a remote control, it is possible to reduce the effects of interference by 10 to 15 decibels.

cision to which they can be set, are extremely useful in measuring very small differentials in time. In various communications as well as counter measure problems this is of extreme value.

Certain applications would ideally call for a smooth delay variation from zero to some finite time. Since it is impossible to have a delay of zero time, Fig. 2 below shows one solution to this problem.

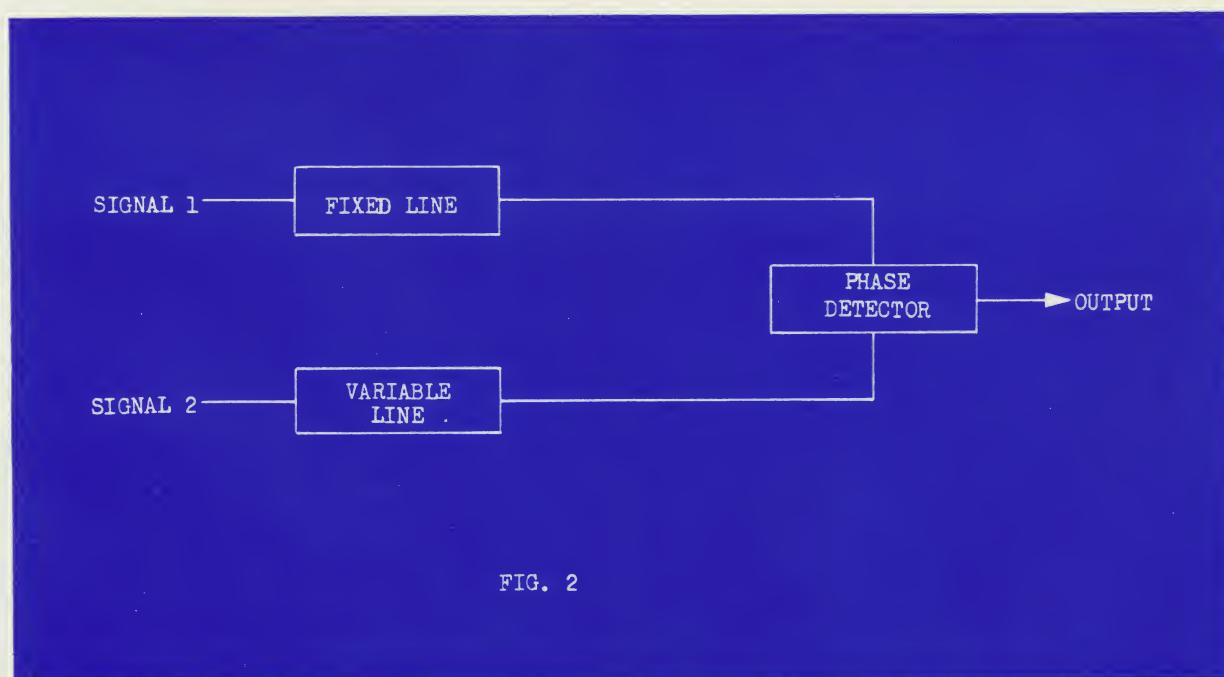


FIG. 2

In Fig. 2, the fixed line has a length equal to the minimum delay of the variable line. Therefore, the relative variation of delay in the variable line starts at zero time.

VARIABLE FREQUENCY OSCILLATOR

- Frequency range variation to 20:1.
- Frequency stability to .01% and better.
- Absolute frequencies possible 500 kc to 300 cps.

Andersen Laboratories variable delay lines can be used as the control element in an extremely stable

variable frequency oscillator having a frequency range as high as 20 to 1. When used in conjunction with a properly designed heating system and Andersen Laboratories proportional temperature controller, Model 785, stabilities approaching that of crystal controlled oscillators can be achieved. Figure 3 below shows functionally how this can be done.

Basically a trigger is continuously recirculated in the above loop. Its period will be primarily that of the delay line. Exact utilization of the output trigger will of course be peculiar to the particular application.

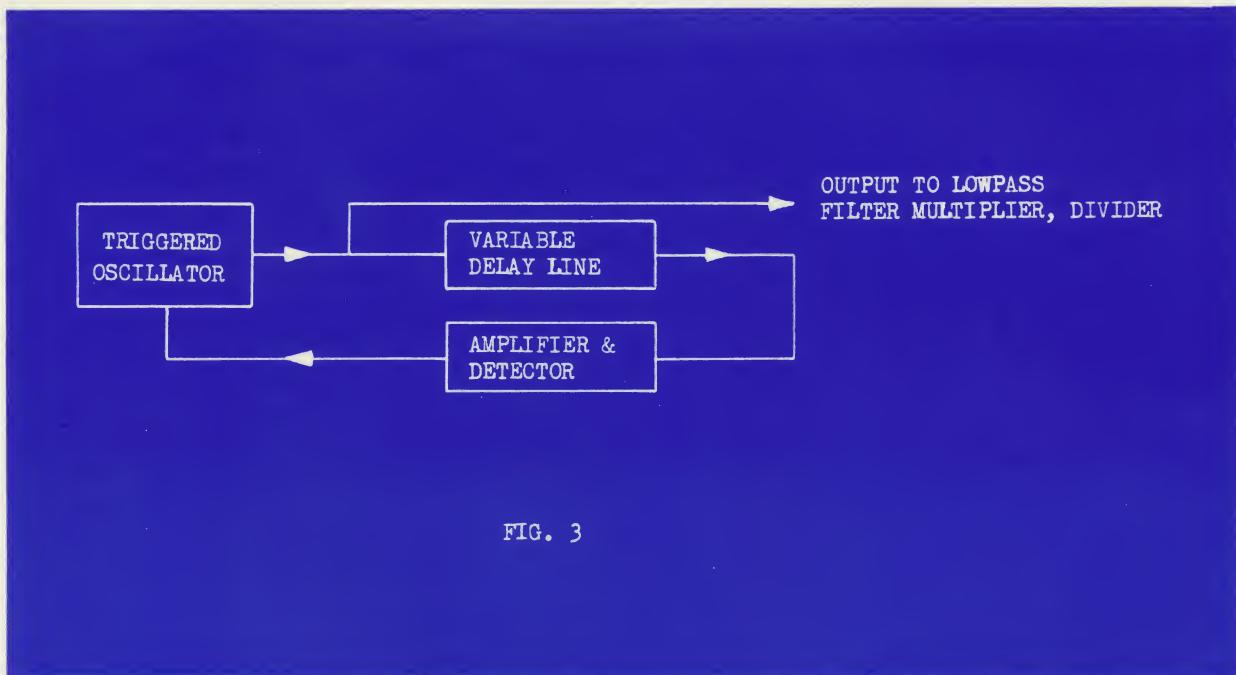


FIG. 3

DESIGN CONSIDERATIONS

Basically, the same design considerations apply in utilizing Andersen Laboratories Variable delay lines as in fixed line applications. It is advisable, however, to be aware of certain differences:

1. Attenuation — commonly 10 db greater than a corresponding fixed line.
2. Variation of attenuation with delay — this does not usually present a problem. Some applications involving high speed variation

can cause a variation in attenuation of as much as 6 db which can be compensated for by proper AGC circuit design.

3. Terminal capacitances — instead of specifying input and output capacitance, it is better to specify overall desired bandwidth and proper terminating impedance and have the units tuned and terminated at the factory.
4. Maximum rate of delay variation—in general, since the mechanical load of the delay line is essentially of a viscous nature, driving power varies as the square of the speed.

5. Carrier frequencies — from 9 to 50 MC are within present production capacity and will be determined in a manner similar to the case of fixed delay lines.
6. Spurious signals — typically variable lines are remarkably free of spurious signals and an extremely smooth pass band can be obtained. Typically the worst spurious is due to triple travel and can be held down to 50 db or better.
7. Bandwidths — electrical bandwidths of 10 MC or better can be readily obtained at a carrier frequency of 30 MC.
8. Packaging — variable delay lines are packaged to meet MIL 945 A and MIL-E-4158 A for temperature, shock, vibration, humidity, dust, etc. Suitable finishes are provided to comply with military requirements.

SYSTEM DESIGN

Many customers are finding it advantageous to have Andersen Laboratories provide pre and post delay circuitry, since our wide experience in this field enables us to provide rapid solution to a problem. Andersen Laboratories is also well qualified to design and construct necessary gear boxes and servo drive systems. There are a number of advantages to customers in having Andersen Laboratories design the entire system including simplicity in drafting the specification, ease of test and tuning and ease in packaging.

Engineers with delay line applications are requested to contact us for further information.

OTHER PRODUCTS:

- ✓ PROPORTIONAL TRANSISTORIZED TEMPERATURE CONTROLLERS
- ✓ SOLID ULTRASONIC DELAY LINES
- ✓ TAPPED ULTRASONIC DELAY LINES



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laboratories
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501 NEW PARK AVE. WEST HARTFORD, CONN.

U.S. PATENT NO.
2,659,053 AND
OTHERS PENDING.

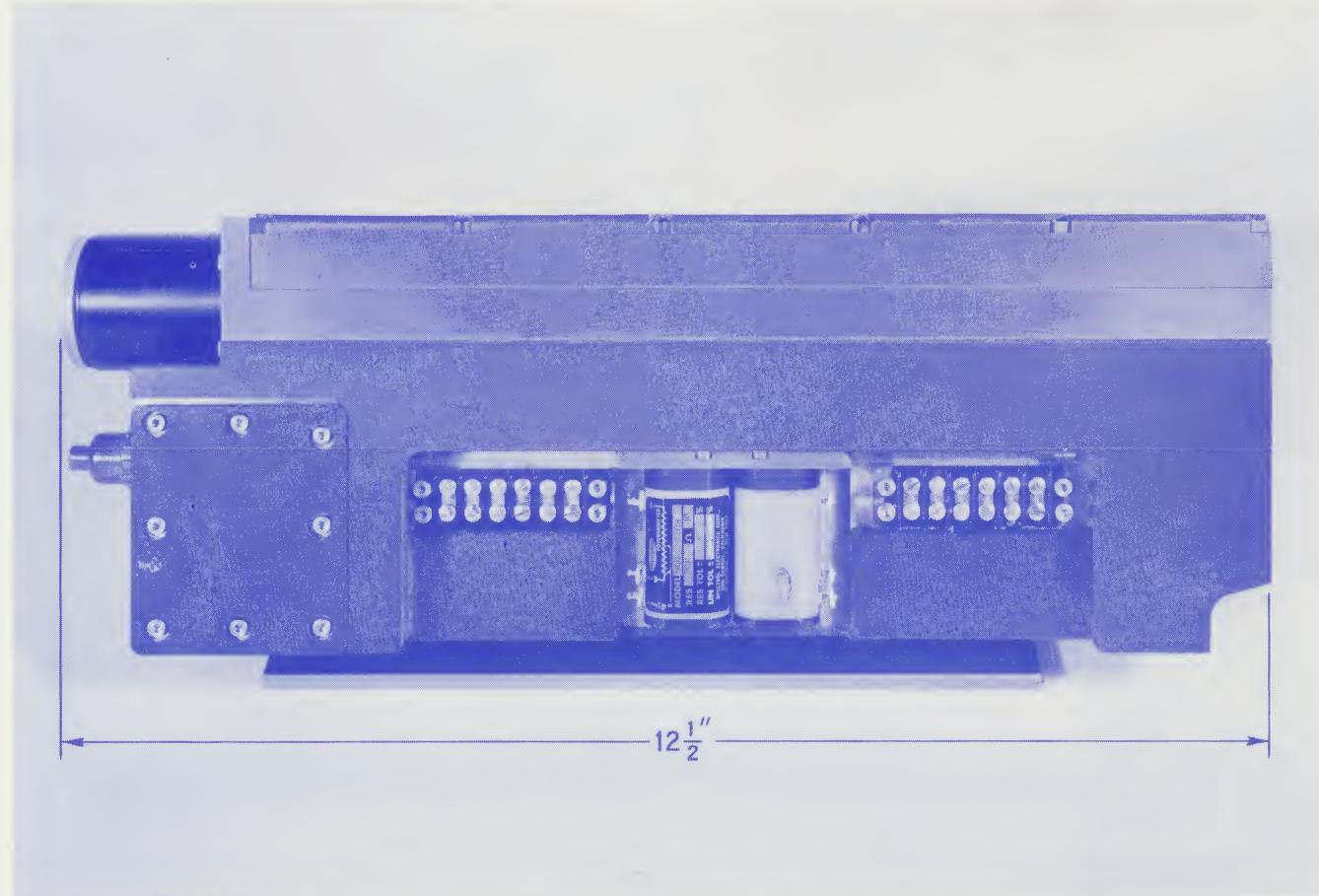
PRINTED IN U.S.A.

Miniaturized Continuously Variable Ultrasonic Delay Lines

Miniature continuously variable ultrasonic delay lines are used for detection, tracking, and ECCM in airborne and satellite systems. Their infinite resolution ensures precise information. The variable delay line is useful as a linear phase shifter, prf adjuster, and a moving target simulator.

SPECIFICATIONS

1. DELAY—Continuously variable from 50 to 170 μ sec.
2. CENTER FREQUENCY—30 megacycles.
3. BAND WIDTH—10 megacycles at 3 db points.
4. SPURIOUS RESPONSE—35 db below main signal.
5. SCAN RATE—Up to 24 μ sec per second.
6. INPUT IMPEDANCE—100 ohms.
7. OUTPUT IMPEDANCE—100 ohms.
8. SIGNAL ATTENUATION—70 db.
9. TUNING CIRCUITS—Accessible from exterior of package.
10. MILITARY SPECIFICATION COMPLIANCE—Meets requirements of Mil-E-5400F.
11. SIZE—12½" x 4¼" x 2¼".
12. Cased in rugged stainless steel.
13. WEIGHT—19 lbs.
14. Includes Drive Motor and Position Potentiometer.



Andersen Laboratories, Incorporated

501 NEW PARK AVENUE
WEST HARTFORD 10, CONN.
PHONE 236-1281

April 13, 1964

TECHNICAL INFORMATION RELEASE

Model II Dispersive Delay Line

Andersen Laboratories announces immediate availability of dispersive delay line designated type II with specifications as follows:

Center Frequency:	30 MC
Variation in Delay:	33.3 μ sec.
Delay at 30 MC:	83.5 μ sec.
Frequency region over which delay is linear with frequency to 1%:	3 MC
Insertion Loss:	45 db
Input Impedance: in parallel with:	17 ohms \pm 5 ohms 100 pf \pm 20 pf
Package Size:	10" x 1/4" x 3/4", aluminum anodized case

Unity gain systems are available on request for specific requirements. Side lobe weighting also available upon request.

Price: \$1785.00 each

Delivery: 3 to 4 weeks

For further information contact Mr. John J. Fitzgerald,
Sales Manager 501 New Park Avenue, West Hartford Connecticut.
Phone AC 203 236-1281.

Andersen Laboratories, Incorporated

501 NEW PARK AVENUE
WEST HARTFORD 10, CONN.
PHONE 236-1281

April 9, 1964

FOR IMMEDIATE RELEASE.....

Andersen Laboratories, Inc. announces the development of a series of 30 mc dispersive delay lines for use in pulse compression systems. The lines vary at the rate of 0.1333 μ sec per mc for each μ sec of delay at 30 mc. The region in which the delay varies linearly with frequency is approximately 3 mc. The linearity in this bandpass is 1%. Variations in delay up to 80 μ sec are possible.

The insertion losses of these devices vary with length and range between 30 and 50 db. Terminal impedances can be adjusted to suit customer applications.

The lines are especially well suited for airborne applications because of their small size and weight. A line with a 100:1 pulse compression ratio can be packaged in a volume 10" x 3/4" x 3/8" and will weigh only a few ounces.

If required, the dispersive delay line can be supplied with Taylor weighting networks and pre and post amplification.

For further information contact Mr. Jason H. Eveleth, Chief Engineer, Andersen Laboratories, West Hartford, Connecticut. 203 236-1281.

electronic products

REPRINT



Tuned amplifier design with integrated circuit (see page 28)

- 27 Magnetostrictive delay lines
- 30 Dummy film resistors
- 32 Capacitance driver circuit

december 1963

product

analysis

Sec. 2350

By Frank Yorrg
Chief Engineer
Andersen Laboratories, Inc.
West Hartford, Conn.

Magnetostrictive Delay Lines

Discussion of three types of delay lines, longitudinal, torsional, and Wiederman. Use a longitudinal line for short delays, with or without taps, with an upper limit of 2 or 3 mc. For long delays, 15 or 20 msec, a torsional line. When long multitapped lines are needed, the Wiederman line is preferable.

THIS ARTICLE EXPLAINS, to design engineers, the problems encountered in the design of magnetostrictive delay lines. When these problems are realized a more practical specification is outlined and a more efficient and reliable product accomplished.

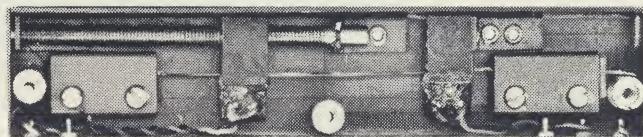
First the article presents problems encountered in longitudinal delay line design. Secondly, it covers torsional and Weiderman lines giving a picture of the present state of magnetostrictive delay lines.

Longitudinal Delay Line Design

The transmission medium, nickel alloy ribbon which has good magnetostrictive properties, is passed through an input and output transducer. At the extreme ends of the delay line the ribbon is secured in place by a damping system. The distance between the input and output transducers determines the delay of the line.

When a current pulse is imposed upon the windings of the input transducer the leading edge of the pulse creates a changing magnetic field, which in turn causes an expansion or contraction of the ribbon. The trailing edge of the pulse causes another expansion or contraction of the ribbon. If the leading and trailing edges of the input pulse are sufficiently close, the two disturbances partially superimpose upon one another. For a constant input pulse width, the distance is determined by the length of the winding in the transducer. The net displacement of the ribbon does not remain fixed, but rather breaks up into two separate disturbances. One propagates to the output transducer, the other to the input damping system. Each of these waves has equal velocities.

The damping system should consist of a very dissipative material, such as rubber, so that all the mechanical energy will be absorbed by the damping. This damping should be capable of maintaining its properties over a wide temperature range -30 to +70°C. This is necessary since the mechanical impedance match



Longitudinal delay line follows the equation:
 $C_L^2 \alpha^2 u / \alpha x^2 = \alpha^2 u / \alpha t^2$

plus the absorbing properties of the damping material must remain constant with temperature or vary at the rate the ribbon material changes. To date, no perfect method of damping has been devised, thus, there are some discontinuities caused at the two damping systems.

Generation of Damping Noise

Most of the mechanical energy is absorbed at the input damping. However, some reflections develop here and propagate down the ribbon to the output transducer. At this time the disturbance generates a voltage in the output coil and this results in an undesired response. However, since the coupling coefficients are very poor at each transducer, part of the reflection continues on to the output damping system. By this time the reflection is of such small magnitude that it is completely absorbed in the damping material.

In the same sense noise can be generated by output damping. One disturbance passes directly through the output transducer when the initial displacement is established at the input. This is the desired delayed signal. Because of the low coefficient of coupling between ribbon and transducer, some of the disturbance continues on to the output damping. Here most of the energy is absorbed, but again some is reflected back to the output transducer. This reflection causes a voltage in the output coils and appears as another undesired signal.

If a single pulse is applied to a magnetostrictive line all reflections appear after the desired delayed signal, since all undesired signals have a longer propagation

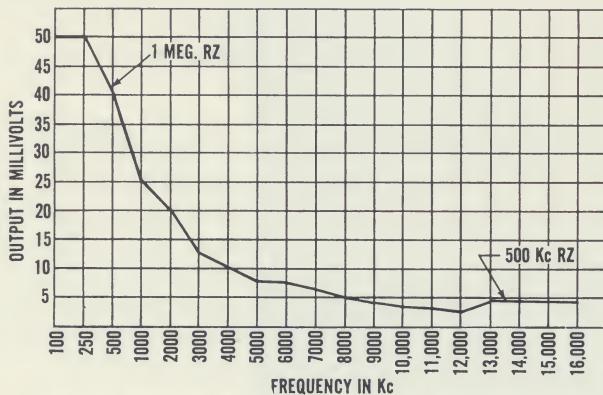
Torsional delay line follows the equation:

$$C_T^2 \alpha^2 \theta / \alpha x^2 = \alpha^2 \theta / \alpha t^2$$

path. The propagation velocity in the longitudinal mode is approximately 0.2×10^6 in/sec or the delay per inch is about 5 μ sec. Thus for a 1 megacycle delay line the mechanical disturbance will be approximately 0.200 in and occurs 5 times in a 1 in damping system. If the delay line is operating at 500 kc a 1 in damping cancels 2.5 cycles. The end result is that the lower the maximum operating frequency of the delay line the longer the damping must become. Conversely, the higher the maximum operating frequency of the line the shorter the damping can be. For good damping, the damping pad should be long enough for 5 cycles to occur within its length. When operating at a low maximum frequency 100 to 400 kc the initial displacement will be larger since the wavelength is longer. This has the advantage of greater output amplitude, but the disadvantage that the longer disturbance is more difficult to damp out. The damping should be less dense for these low maximum frequency delay lines. One way of avoiding this problem is to design the delay line for a high maximum bit rate. If the input pulse width is narrowed to 40 or 50 per cent of the high rep. rate pulse period, the delay line operates at the high frequency with a spacing of 1 or more microseconds between pulses. The most practical and the most common input pulse widths are between 0.3 and 1.0 μ sec. The 500 to 1,000 kc line is a conventional type and less expensive than the 100 kc line, which requires longer input and output winding lengths, and longer damping systems. This is true for both longitudinal and torsional delay lines.

Disadvantages of Longitudinal Line

The longitudinal delay line has two disadvantages in comparison to the torsional delay line:



Delay versus output level for an input of 60 milliamperes and 200-ohm source.

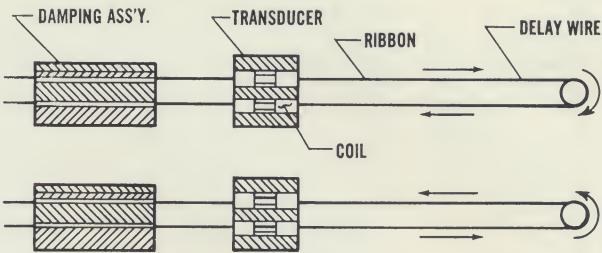


Fig. 1. A current input to the two transducers sets up a longitudinal push-pull arrangement in the two ribbon assemblies.

1. **The dispersion effects are much greater in the longitudinal mode.** Consider a long continuously variable longitudinal delay line. As the delay is increased from its minimum point the polarity of the pulse gradually changes and eventually reverses itself when the line is long. During this process dispersion causes a continuous degradation in frequency response. Reversal of the pulse polarity can be compensated in the amplifying circuitry. This type of line is frequently used as a time or range marking device. Continuously variable longitudinal delay lines can be made up to approximately 100 microseconds without appreciable distortion due to dispersion.

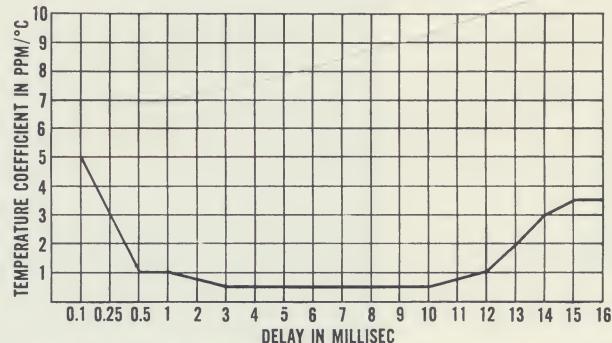
2. **The temperature coefficient (T.C.) is not as good as the torsional delay line.** The best magnetostrictive materials are not the best constant modulus materials. However, most longitudinal lines are made with a good magnetostrictive material to give maximum conversion of energy (electrical to mechanical and mechanical back to electrical). These materials vary from 10 to 200 PPM/ $^{\circ}$ C. Constant modulus alloys can be used in the longitudinal mode at the increase of insertion loss.

One advantage to the longitudinal delay line is that taps can be added without any appreciable degradation in the signal to noise ratio. The standard signal to noise ratio for a magnetostrictive line (single pulse basis) is 20 or 30 to 1. When taps are added to a longitudinal line additional transducers are put on the ribbons. There is no major discontinuity caused and as a result, the signal to noise ratio remains constant. The taps are made adjustable if desired.

Torsional Delay Lines

The torsional delay line is a refinement of the ideas developed in the use of longitudinal delay lines. The damping systems remain the same. Each transducer has 2 coils which are wired up in a push-pull series. Ribbons are passed through each coil and are attached to a constant modulus wire. When a current pulse is imposed on the input transducer a longitudinal push-pull arrange-

(Continued on Page 62)



Temperature coefficient versus delay, 0 to 60°C, for torsional lines.

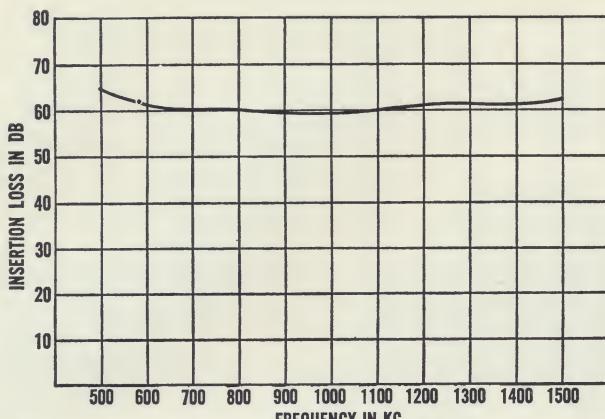


Fig. 2. Typical curve for a 3,000- μ sec delay line.

ment is set up in the 2 ribbon assemblies as shown in Fig. 1. This push-pull initiates a torsional motion in the constant modulus wire. The torsional disturbance travels down the wire to the output ribbons. Here the torsional motion sets up another longitudinal push-pull condition, which in turn induces a voltage in the coils of the output transducer. Most delay lines are made in the torsional mode. The main reasons for this are: less dispersion in the torsional mode; temperature coefficient is better in the torsional mode. The ribbons used in the longitudinal line and in the longitudinal portions of the torsional line are not constant modulus alloys. The wire used in the torsional mode does not have to be a good magnetostrictive material but must be a constant modulus material. The constant modulus alloys can be heat treated to adjust the modulus and this is done to give a good temperature coefficient of delay for a magnetostrictive delay line.

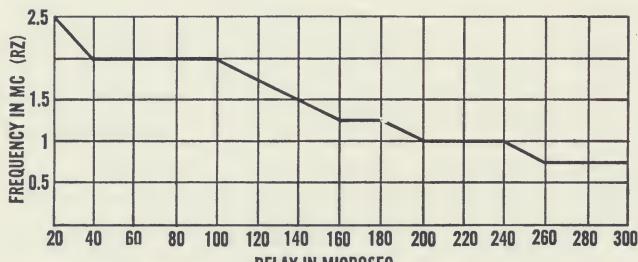
Example

The temperature coefficient of the ribbon material being used in longitudinal sections of a torsional line is 50 PPM/ $^{\circ}$ C. Then for a particular length of wire to be used in a particular diameter a specific heat treatment is performed on the wire to make the wire negative enough to compensate for the positive temperature coefficient of the ribbon. In this manner temperature coefficient as low as 0.25 PPM/ $^{\circ}$ C can be obtained:

LONGITUDINAL

$V_L = \sqrt{\frac{E}{D}}$ where E = Young's modulus, D = Density, V_L = Propagation velocity in the longitudinal mode.

$$V_L^2 = \frac{E}{D}, \therefore \frac{dV}{V} = \frac{dE}{2E} - \frac{dD}{2D}$$



Typical curve for the delay versus frequency characteristics of a longitudinal line.

$$D = \frac{\text{Mass}}{\text{Volume}}, V_1 = \text{Volume}$$

If the mass is constant For a cross section

$$\frac{dD}{D} = -\frac{dV_1}{V_1} \quad \frac{dV_1}{V_1} = \frac{3dl}{l}$$

Time or Delay = $\frac{\text{Length of Line}}{\text{Velocity}}$

$$\frac{dT}{T} = \frac{dl}{l} - \frac{dV}{V}, \therefore \frac{dT}{T} = \frac{dl}{l} - \left[\frac{dE}{2E} - \frac{dD}{2D} \right]$$

$$\text{But, } \frac{dD}{D} = -\frac{dV_1}{V_1}, \therefore \frac{dD}{D} = -\frac{3dl}{l}$$

$$\frac{dT}{T} = \frac{dl}{l} - \frac{dE}{2E} - \frac{3dl}{2l}, \therefore \frac{dT}{T} = -\frac{1}{2} \left[\frac{dl}{l} + \frac{dE}{E} \right]$$

$$\text{If } \frac{dT}{T} = 0, \frac{dl}{l} = -\frac{dE}{E}$$

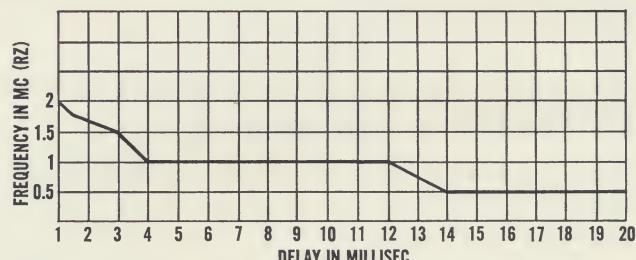
Thus, the ideal case is to have dl/l equal and opposite to dE/E for a constant modulus material.

TORSIONAL

$$V_T = \sqrt{\frac{E_s}{D}} \text{ where } E_s = \text{Shear modulus, } D = \text{Density, } V_T = \text{Velocity of propagation in the torsional mode.}$$

Torsional delay lines have a lower limit caused by the physical size of components used. The smallest delay obtainable in the torsional mode is approximately 20 microseconds. Also the temperature coefficient of a very short torsional line may begin to increase, since we are not using very much wire to compensate for the temperature coefficient of the ribbon material.

Taps are added to a torsional delay line by attaching ribbons to the wire at the desired point. Then the ribbons are passed through a transducer in a conventional manner. Depending upon the length of the delay line, not more than 4 taps should be used if the taps are brought off the wire by means of ribbons (other than the normal input and output ribbons). The reason for this is that each junction of the ribbons to the wire is a discontinuity and causes a spurious signal. Depending on the number of taps and length of the line signal to noise ratio may degrade to 10-1 (single pulse basis).



Typical curve shows frequency versus delay for torsional lines.

Magnetostrictive delay lines can also be used for analog applications. Figure 2 is a typical curve for a 3,000 μ sec delay line. Regardless of what type of magnetostrictive delay line used there is one property common to all, the amplitude of the output pulse varies with temperature. This variation can be controlled anywhere from 5 to 60 per cent depending on the particular specification. Another phenomena which is common to both lines is that humidity affects the delay of the line. \oplus

REFERENCE

- Scarrott and Naylor, "Wire Type Acoustic Delay Lines for Digital Storage," Proc of the Institute of Electrical Engineers, 1956 vol. 103, Part B.

Andersen Laboratories, Incorporated

501 NEW PARK AVENUE
WEST HARTFORD 10, CONN.
PHONE 236-1281

April 13, 1964

FOR IMMEDIATE RELEASE

Electrically Variable Delay Lines, an Andersen Laboratories product, offers a unique approach to pulse positioning and phase control. The EVDL features the advantage of controlling delay by electrical rather than mechanical means.

Electrically Variable Delay Lines provide a new method for the solution of problems in transmission time control, pulse control and shaping, high frequency phase control, pulse time modulation, and phase or frequency modulation.

Designed and built for either carrier or pulse type applications, these Electrically Variable Delay Lines can be produced within a wide range of operating characteristics. They are highly adaptable to transistorized circuitry and will withstand extreme humidity, shock, and vibration.

TYPICAL SPECIFICATIONS:

Delay Bandwidth Product	10 mc, μ s maximum
Max/Min Delay Ratio	7:1 maximum
Delay To Rise Time Ratio	20:1 maximum
Characteristic Impedance	50 to 5000 Ω

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April 14, 1964

NEWS RELEASE

Andersen Laboratories, Inc., announces the availability of an L-C Continuously Variable Delay Line with a $T_d = 0 - 28$ nanosecs; Characteristic Impedance - 90 ohms. Unit size is 2" diameter by 3.88" length. Operating Frequency is 15 Mc.

The delay line is used as a quartz delay line adjustment or for IF Strip Trimming. Resolution is $1/2^\circ$ or better.

For further information write Andersen Laboratories, Incorporated, 501 New Park Avenue, West Hartford, Connecticut, Tel # 236-1281 - Attention: Sales Manager.



Serving the National Defense in the Fields of:

- BALLISTIC MISSILE DETECTION
- SATELLITE COMMUNICATIONS
- TARGET SIMULATION
- ELECTRONIC COUNTERMEASURES
- MISSILE GUIDANCE
- INFORMATION STORAGE

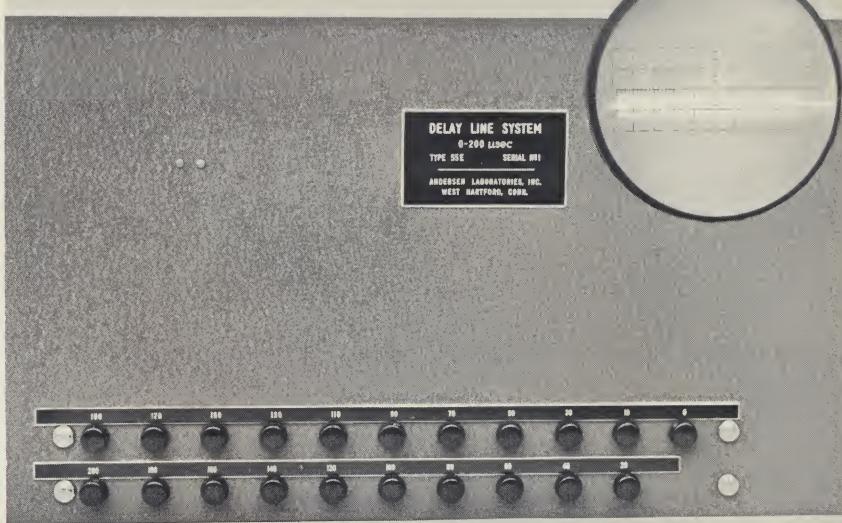
Serving the Air Transport Industry in the Fields of:

- MOVING TARGET INDICATOR SETS
- AIRPORT FLIGHT STACKING EQUIPMENT
- AIRPORT SURVEILLANCE RADARS
- ALTITUDE FINDING EQUIPMENT

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Delay Network used in Satellite Communication

This device is used to study the effects of scattering on a signal which is reflected from a layer of needles. These needles will be put into space to function as a man-made ionosphere. The device shown provides delays from zero to 200 microseconds in 10 microsecond intervals. The output pulses are individually adjustable in amplitude to simulate various reflection problems. The insert shows twenty individual pulses adjusted to approximately equal amplitude.

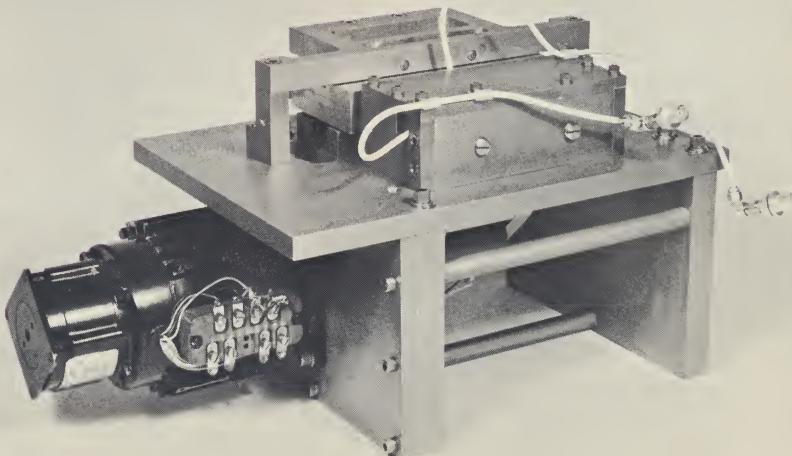


Delay Network used in Ballistic Missile Detection System

Radar engineers have been searching for new techniques to solve the problem of ballistic missile detection and tracking. One promising new approach utilizes the delay network shown above. The underlying technical principle is the signal to noise improvement resulting from utilizing a very wide transmitted pulse to give a much larger average transmitted power and then processing the received information through the delay network so that the definition of a narrow pulse system will be achieved.

Variable Delay Line used as Parallax Corrector

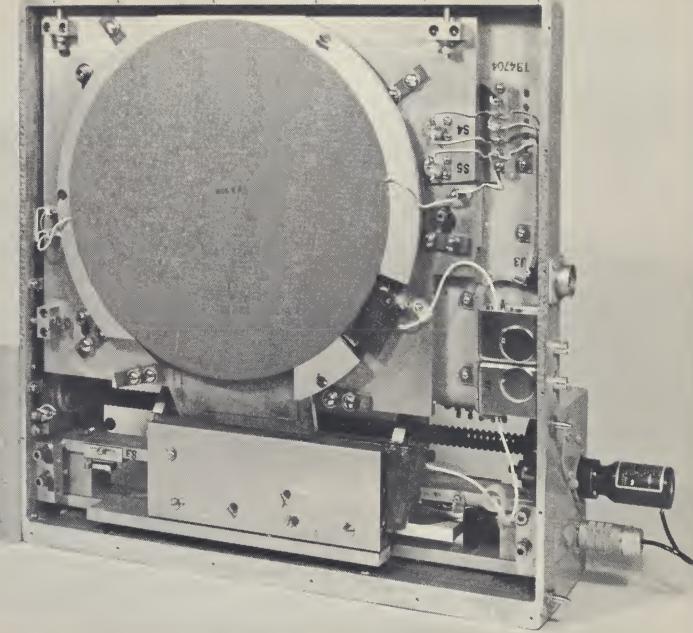
The unit shown, when associated with other circuitry, is used as an antenna parallax corrector in a prototype airport 3-D radar system. Airport systems now in use do not show aircraft altitude, an increasingly vital statistic with today's crowded air space. The altitude finding device, of which this unit is a part, is designed for an accuracy of 500 feet at 50 miles (unshown are the IF amplifiers, servo chassis and power supply, also manufactured at Andersen Laboratories).



Variable Delay Line used as a Filter

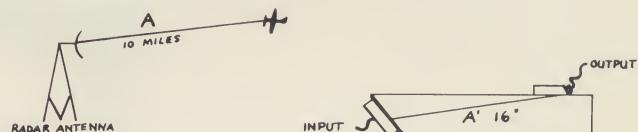
This equipment, similar to World War II IFF (Information Friend or Foe) is part of the Federal Aviation Agency's program of airport safety and makes possible more efficient utilization of available facilities and air space.

An aircraft is supplied with a transponder which transmits a code on signal. This code positively identifies the approaching airplane. Since undesired signals are received with the code, a device for rejecting them is necessary. The unit shown is an integral part of an equipment called the Beacon De Fruiter.



Servo Controlled Variable Delay Line System for Target Simulation

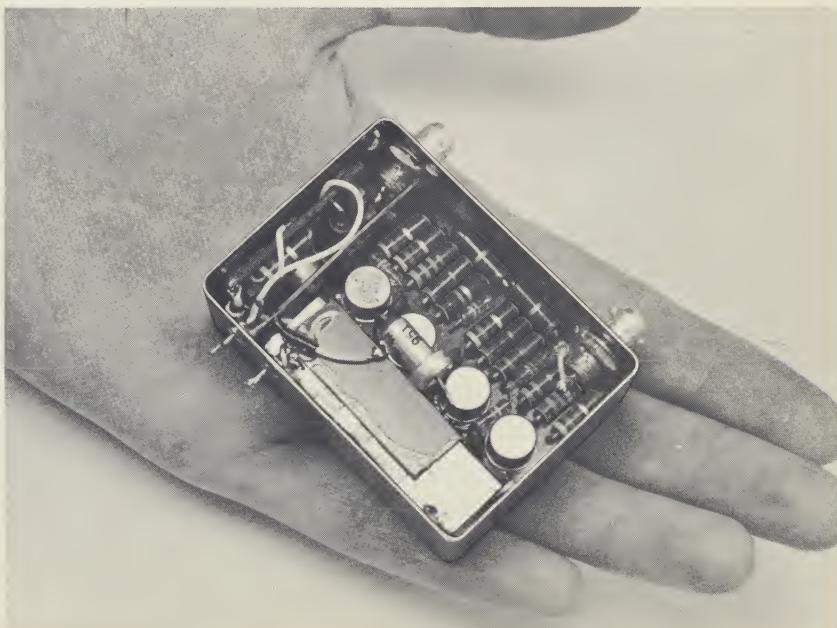
This device is used to simulate targets in order to check out a counter measures system. A single command function causes the delay line to vary in length at the appropriate velocity. Targets traveling up to 20,000 feet per second can be simulated with this device and appropriate checkouts made. One function of the device can be seen in this simple illustration.



The pulse path-length A^1 is equal to the target range A in time.

Transistorized Serial Type Memory Device

Utilizing a quartz delay line, this device stores 65 bits of information at a 10 megacycle counting rate with an access time of less than 4 microseconds. It may replace other components now used in digital computers which are substantially larger in size and cost. In this application this is the first time that a high speed, short delay package has been achieved. This unit operates at a counting speed over ten times greater than was heretofore practical with acoustic delay lines.



Modern, complex, electronic systems require storage, comparison, evaluation and programming of many pieces of information in order to reach a decision. Andersen's contribution is in improving and developing more sophisticated methods for the control and utilization of time. This control of time is achieved through the use of delay lines as circuit elements. Andersen has been foremost in the development of delay lines since the inception of the industry in 1950.

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Pictured above is the ultrasonic path in a 17 sided polygon of fused quartz.